SUPPLY CHAIN RESILIENCE:
DEVELOPMENT OF A CONCEPTUAL FRAMEWORK, AN ASSESSMENT TOOL AND AN IMPLEMENTATION PROCESS

DISSERTATION

Presented in Partial Fulfillment of the Requirements
for the Degree Doctor of Philosophy
in the Graduate School of The Ohio State University

by

Timothy J. Pettit, M.S.

* * * * *

The Ohio State University
2008

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ABSTRACT

The business environment is always changing and change creates risk. Managing the risk of the uncertain future is a challenge that requires resilience – the ability to survive, adapt and grow in the face of turbulent change. Academics and industry leaders have seen the need to supplement traditional risk management techniques with the concept of resilience that is better designed to cope with extreme complexities, unpredictable events and adaptive threats. However, without standardized definitions, accepted variables or measurement tools, supply chain resilience is merely a theoretical concept. This dissertation will explore the current thought on supply chain resilience and develop the construct into a managerial process for implementation.

In Phase I, the Supply Chain Resilience Framework was developed to provide a conceptual framework based on extant literature and refined through a focus group methodology. Findings suggest that supply chain resilience can be assessed in terms of two dimensions: vulnerabilities and capabilities. Research identified seven vulnerability factors composed of 40 specific attributes and 14 capability factors from 71 attributes that facilitate the measurement of resilience.

Phase II created an assessment tool based on this framework – the Supply Chain Resilience Assessment and Management (SCRAM™). Data gathered from seven global manufacturing supply chains was used to assess their current state of supply chain

resilience. The tool was validated using a qualitative methodology comparing assessment scores to 1,369 items recorded from discussions of 14 recent disruptions.

Phase III concluded the research project by identifying critical linkages between the inherent vulnerability factors and controllable capability factors. Accomplished through a mixed-method triangulation of theoretical linkages, assessment correlations and focus group connections, research identified 311 specific linkages that can be used to guide a resilience improvement process.

An implementation process is proposed to guide supply chain leaders toward the goal of creating and maintaining a dynamic state of balanced resilience by developing a portfolio of capabilities best matched to the pattern of inherent vulnerabilities. Exploratory data suggests that we can infer a correlation between increased resilience and improved supply chain performance. Each phase of this study concludes with discussion of limitations and recommendations for future research.

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DEDICATION

Dedicated to my father and mother, Bob and Kathy Pettit, for supporting our family and sharing their commitment to education so we all could reach our full potential.

ACKNOWLEDGMENTS

The impetus for this research began in late 2005 as the Center for Resilience at The Ohio State University hosted a symposium to begin their study on supply chain resilience. Dr. Joseph Fiksel, as co-director and now Executive Director, hosted key speakers including Dr. Yossi Sheffi (MIT), Dr. Keely Croxton (OSU) and Mr. Nick LaHowchic (Limited Brands, Inc.), each highlighting the emerging need for understanding and implementing resilience concepts in supply chain management. Dr. Fiksel's early work provided the foundation for the development of the conceptual framework presented here. His insight and guidance on research, interviewing and writing skills was in the true form of a mentor – encouraging and challenging. My sincerest appreciation for your contributions.

Following the Center for Resilience's kick-off symposium, Dr. Keely Croxton linked the construct of resilience in business with the imperative for resilience in military operations. I am grateful to Dr. Croxton for connecting me with this research opportunity and continuing on the research team to add significant direction in refining the resilience concepts. As academic advisor and dissertation advisor, I am grateful to Dr. Croxton for her caring and concern while maintaining strict academic rigor through coursework and research.

Even before this project started, Dr. Martha Cooper is recognized for "selling me" on the Fisher College of Business as a world-class educational institution. As a visiting

faculty to the Air Force Institute of Technology, Wright-Patterson Air Force Base, in Dayton, Ohio, Dr. Cooper earned my appreciation for her assistance in my application process to the doctoral program in logistics management as well as her excellent teaching skills and advice.

Dr. Walter Zinn provided a pivotal role on the dissertation committee. I am thankful for his wisdom in designing an achievable dissertation proposal that included rigorous tactics for ensuring research validity and reliability that is crucial to grounded studies. As a side note, I enjoyed working with another flying enthusiast.

To my fellow PhD students – Francois, Matias, Ned and Rudi – thank you whole-heartedly for the long discussions on logistics topics. Your time spent reviewing my draft papers was very much appreciated. All of you were instrumental in critiquing the initial assessment tool and made significant contributions to this work.

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However, the most important contribution to this work came from my family for their unconditional support during my long hours on-the-road, studying, interviewing and writing. I enjoyed the "flexible" time that we could spend together over the past three years and look forward to many, many great years to come. To my children: Dillon,

Cheradyn and Elena, I am proud of you and wish you the best in life, and I encourage you to pursue your dreams no matter what form they take. To Coeann, the love of my life, you may consider these past three years as "the worst" versus "the better", but I know in my heart that God has surely blessed me through all of these years by bringing us together. Our love will always grow ….

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PUBLICATIONS

1. Pettit, Timothy J., Joseph Fiksel and Keely L. Croxton (2008), "Ensuring supply chain resilience: Development of a conceptual framework," *Journal of Business Logistics*, conditionally accepted.
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4. Pettit, Timothy J. and Joseph P. Dougherty (1997), "Identifying situational constraints to focus quality improvement in an Air Force aerial port," *Air Force Journal of Logistics*, Vol. 21, No. 1, pp. 22-24.

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CHAPTER 1

INTRODUCTION[1]

The business environment is always changing and change creates risk. According to Deborah Wince-Smith, President of the Council on Competitiveness, "managing this rapidly changing risk landscape is an emerging competitiveness challenge—a challenge that demands resilience" (Council on Competitiveness 2007). Supply chain leaders, guest speakers and consultants are all using this buzzword, but what is resilience? How can you measure it? In order to meet the challenge of creating and maintaining resilience, we must first define the construct of resilience for supply chains. This research, a collaborative project with the Center for Resilience and the Fisher College of Business at The Ohio State University, will evaluate the construct of resilience in three phases: 1) review the current state of thought on supply chain resilience and develop a theoretical framework through extant literature and empirical data, 2) create and validate a resilience assessment tool and 3) identify critical linkages between resilience factors to guide supply chain leaders to better manage resilience.

[1] This chapter partially extracted from previously published work by Pettit, Timothy J., Joseph Fiksel and Keely L. Croxton (2008), "Can you Measure your Supply Chain Resilience?," *Supply Chain and Logistics Journal*, Vol. 10, No. 1, pp. 21-22.

When Just-in-Time Stops

Why is supply chain resilience important? To start with an example, a natural disaster brought most of Japan's automobile manufacturers to a halt for several days. On July 16, 2007, a 6.8 magnitude earthquake in central Japan severely damaged the facilities of Riken Corp., a supplier of automobile components including specialized piston rings. Riken had chosen to locate all of its plants in a single area of Japan to increase efficiency, but this strategic decision combined with Just-in-Time deliveries made the entire production capacity vulnerable to a catastrophic incident (Chozich 2007). Firms must determine whether the expected benefits of policies such as centralization and limited sourcing outweigh the costs of potential disruptions. However, in order to make this decision, supply chain managers must be able to measure their current state of resilience and evaluate options to reach their desired state of resilience.

What is Resilience?

Resilience is defined as the capacity of a system to survive, adapt and grow in the face of turbulent change (Fiksel 2006). Resilience is a feature of complex systems such as companies, cities or ecosystems. Systems evolve through cycles of growth, accumulation, crisis and renewal, and even self-organize into new, more desirable configurations. Business systems face technological change, financial risk, political turbulence and mounting regulatory pressures; industrial growth does not proceed smoothly.

The traditional tool to manage uncertainty is risk management, which is especially challenging when threats are unpredictable. Deliberate threats such as theft or terrorism can even adapt to new security measures. At the same time, corporations are accepting broader responsibility for the social and environmental impacts of their supply chains. The entire enterprise has a role to play in creating and maintaining supply chain resilience. A resilient supply chain has the capacity to overcome disruptions and continually transform itself to meet the changing needs and expectations of its customers, shareholders and other stakeholders.

Supply Chain Resilience

All firms rely on their suppliers to maintain smooth operations and their customers for continued revenue. Therefore, a resilient firm is truly only as resilient as its supply chain. Jack Welch, former CEO of GE, wrote in a *Business Week* segment that resilience should be on every manager's must-have list "because anyone who is really in the game messes up at some point" (Welch and Welch 2007). He concludes that "the most successful people in any job always own their failures, learn from them, regroup and then start again with renewed speed, vigor and conviction." Anticipating, identifying, reacting and learning are all at the heart of resilience.

The remainder of this dissertation is presented with three separate essays and a uniting conclusion. Chapter 2 will develop a Supply Chain Resilience Framework, which offers a basis for defining the construct of resilience within a supply chain in terms of measurable variables. The next step in the process is presented in Chapter 3

with the creation and validation of an assessment tool, the Supply Chain Resilience Assessment and Management (SCRAM^{TM}), which can be administered within any product-focused supply chain. Once assessed, the implementation of resilience improvement is now possible through the focused management of critical linkages empirically derived in Chapter 4. And finally, although many managers and educators are using various terminologies for resilience, Chapter 5 reiterates the immediate need for implementing the concept of supply chain resilience as defined by the Supply Chain Resilience Framework and summarizes the contributions of this research toward meeting that need through the application of the SCRAM^{TM} tool in conjunction with a resilience improvement process.

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CHAPTER 2

DEVELOPMENT OF A CONCEPTUAL FRAMEWORK[2]

"The only constant is change."
– *Heraclitus, 6th century B.C. Greek philosopher*

INTRODUCTION

Supply chains are complex networks of enterprises that experience continual turbulence, creating a potential for unpredictable disruptions. In fact, executives identify supply chain risk as the highest threat to their firms (FM Global 2007). Studies by the Council for Competitiveness found that, although effectively managing such operational risks directly affects financial performance, a majority of corporate board members were under-informed about those risks (Council on Competitiveness 2007). Furthermore, traditional risk management techniques are lacking in their ability to assess the complexities of supply chains, evaluate the intricate interdependencies of threats and prepare a firm for the unknowns of the future (Hertz and Thomas 1983; Starr, Newfrock and Delurey 2003). As they become aware of these gaps, many supply chain researchers

[2] This chapter previously submitted for publication, Pettit, Timothy J., Joseph Fiksel and Keely L. Croxton (2008), "Ensuring supply chain resilience: Development of a conceptual framework," *Journal of Business Logistics*, conditionally accepted.

are beginning to understand the value of the concept of resilience, defined as "*the capacity for an enterprise to survive, adapt and grow in the face of turbulent change*" (Fiksel 2006). This study builds on lessons learned from supply chain disruptions to create a conceptual framework for evaluating and improving supply chain resilience.

Although there are many definitions of a "supply chain", research into supply chain resilience must take a broad view in order to capture the dynamics of turbulence and complexity. Therefore, we define a supply chain as *the network of companies involved in the upstream and downstream flows of products, services, finances and information from the initial supplier to the ultimate customer* (Christopher 1992; Mentzer et al. 2001; Lambert, García-Dastugue and Croxton 2005). The vast degree of turbulence and complexity in supply chains requires an enterprise view with collaboration among all business functions within the firm (Ahlquist et al. 2003), as well as inter-organizational alignment among supply chain members (Lambert 2006; Slone, Mentzer and Dittman 2007). However, as a result of environmental changes, supply chains are becoming more complex and more vulnerable, thus contributing to potential supply chain disruptions (see Table 2.1).

- Globalized supply chains
- Specialized factories
- Centralized distribution
- Increased outsourcing
- Reduced supplier base
- Increased volatility of demand
- Technological innovations

Adapted from: *Supply Chain Vulnerability: Executive Report*, School of Management, Cranfield University, 2002.

Table 2.1: Factors Increasing the Potential for Supply Chain Disruptions

An example demonstrates the importance of even small disruptions to the automotive manufacturing supply chain. On July 16, 2007, a magnitude 6.8 earthquake in central Japan severely damaged the facilities of Riken Corp., a supplier of automobile components including specialized piston rings. Riken had located all of its plants in a single area of Japan to increase efficiency, making the entire production capacity vulnerable to a catastrophic incident (Chozick 2007). Earthquake damage to Riken facilities and its utilities completely shut down production for one week and required another week of repairs to return to full output. As a result of carrying limited inventories, Toyota, one of Riken's many customers, was highly vulnerable to production and transportation disruptions. Toyota's sourcing strategy emphasized close relationships with a limited number of suppliers, but in this case Toyota was forced to shut down all 12 of its domestic assembly plants, delaying production of approximately 55,000 vehicles.

Supply chain managers are becoming increasingly aware of these vulnerabilities. A study found that at the time a disruption is announced, the average shareholder return immediately drops 7.5 percent (Singhal and Hendricks 2002). Four months after a

disruption, the total loss grows to an average of 18.5 percent. Therefore, organizations must learn to anticipate, absorb and overcome disruptions (Pickett 2006). However, a comprehensive solution requires a new focus on mitigating risk that "extends beyond the four walls of the single firm" (Christopher and Peck 2004b). Managing supply chain resilience is a proactive method that can complement and enhance traditional risk management and business continuity planning.

This chapter develops the concept of supply chain resilience through a review of the literature on supply chain vulnerabilities and the techniques used to anticipate, mitigate and overcome disruptions. Following this review, we posit several research propositions with regards to the concept of supply chain resilience, then present a conceptual framework based on extant literature and refined through insight from focus groups conducted at Limited Brands, Inc. The chapter concludes with managerial implications for using supply chain resilience to gain a competitive advantage and future research recommendations.

CONCEPTUAL FOUNDATIONS

Many tools and methods have been proposed to help businesses cope with continual change and survive in the long-term. In this section, we briefly review those methods, both old and new, that have contributed to dealing with supply chain disruptions. These provide a foundation for the concept of supply chain resilience.

Dealing with Uncertainty in Supply Chains

The industrial revolution and inter-city transport of goods motivated the use of inventory as the primary method of decoupling production from demand and combating the myriad of uncertainties throughout the system. Ford W. Harris' Economic Order Quantity (EOQ) model (Harris 1913) was later adapted to account for uncertainty in lead-time and demand (see Whitin 1954). Adding safety stock to cycle stock extended the use of inventory as the primary buffer against uncertainty for decades.

The era of customer focus in the 1970s brought service to the forefront (Kent and Flint 1997). Hence, balancing customer satisfaction against inventory carrying costs, productivity and distribution costs became the focus of logistics managers. To manage the interaction of supply and demand risks, methods were developed for Quick Response, using policies such as Just-in-Time (JIT), Vendor Managed Inventory (VMI) and Continuous Replenishment (see Zinn and Charnes 2005; Schwarz and Weng 2000; Waller, Johnson and Davis 1999; Herron 1987, respectively). However, this new dependence on time-definite transportation re-opened old supply chain issues, as safety stocks were dramatically reduced, and supply and demand were more closely coupled. In other words, Quick Response systems increase the brittleness of supply chains by imposing connectivity requirements and reducing inventory buffers (Monahan, Laudicina and Attis 2003). This brittleness may be offset through increased responsiveness based on shorter lead-times; however, in such a highly-constrained system disruptions can be disastrous (McBeath 2004).

The 1980s and 1990s saw increasing globalization and implementation of lean manufacturing as measures continuing cost reductions. Lean manufacturing, as in the Toyota Production System, can be defined as a "*systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection*" (Optiprise 2006). However, these process improvements yield mixed benefits in terms of resistance to vulnerabilities. For example, with less inventory at each processing step there is less buffer capacity for disruptions and less opportunity for innovation (Melnyk 2007). Christopher and Rutherford (2004) recommend that one way to avoid "leaning down too far" is to integrate the expected cost of recovery into the total cost equation so an optimum level of leanness can be identified. This is obviously a difficult undertaking with significant resources utilized to gather data, estimate future states and enumerate potential actions-reactions.

Another important management tool that was developed through the 1980s and 1990s is Six Sigma, which also has mixed benefits for resisting vulnerabilities. Six Sigma provides a methodology for continuous process improvement with a goal of squeezing out process variability to achieve less than 3.4 defects per million. Once again, finely-tuned processes may not be robust enough to absorb input disruptions without bending or breaking (Christopher and Rutherford 2004). Forcing a system into very small variance can create resistance to change with little flexibility. As an alternative, "robustness can be achieved through resilience rather than resistance" (Fiksel 2003).

Resilience Approaches

To incorporate the concept of resilience into management theory, we will present the use of the term "resilience" in a variety of non-business fields and discuss lessons that can be applied to the study of supply chain resilience. The concept of resilience is used extensively in engineering, ecological sciences and organizational research, all of which provide insight into creating a conceptual framework for supply chain resilience.

A very basic definition of resilience can be found in engineering: "*the tendency of a material to return to its original shape after the removal of a stress that has produced elastic strain*" (Merriam-Webster 2007). However, it may be beneficial for a supply chain not to return to its original "shape" following a disruption, but rather to learn from the disturbance and adapt into a new configuration.

In the ecological sciences, the standard definition of resilience is "*the ability for an ecosystem to rebound from a disturbance while maintaining diversity, integrity and ecological processes*" (Folke et al. 2004). The concept of adaptability is crucial to living systems, and supply chains may be seen as a network of "living" systems. Based on this systems concept, Fiksel (2003) proposed four major characteristics of resilient systems: diversity, efficiency, adaptability and cohesion.

Finally, the concept of resilience has been studied in organizational leadership. According to Dean Becker, president and CEO of Adaptive Learning Systems, "More than education, more than experience, more than training, a person's level of resilience will determine who succeeds and who fails" (Coutu 2002). Therefore, creating resilient leaders "is the best way to ensure that your organization will prosper in a very chaotic

and uncertain future," and those resilient organizations consistently outlast their less resilient competitors (Stoltz 2004).

Resilience in Supply Chains

The concept of resilience in supply chains combines these previous tenets with studies of supply chain vulnerability, defined by Svensson (2002) as "*unexpected deviations from the norm and their negative consequences.*" Mathematically, vulnerability can be measured in terms of "risk", a combination of the likelihood of an event and its potential severity (Sheffi 2005; Craighead et al. 2007). Both these definitions have foundations in traditional risk management techniques and are expanded by other authors (Svensson 2000, 2002, 2004; Chapman et al. 2002; Zsidisin 2003; Peck 2005).

The first wide-spread study on supply chain resilience began in the United Kingdom, following transportation disruptions from fuel protests in 2000 and the outbreak of the Foot and Mouth Disease in early 2001. The study explored the UK's industrial knowledge base about supply chain vulnerabilities and found that: 1) supply chain vulnerability is an important business issue, 2) little research exists into supply chain vulnerability, 3) awareness of the subject is poor and 4) a methodology is needed for managing supply chain vulnerability (Cranfield University 2003).

Based on this empirical research, Christopher and Peck (2004b) developed an initial framework for a resilient supply chain. They asserted that supply chain resilience can be created through four key principles: 1) resilience can be built into a system in advance of a disruption (i.e. re-engineering), 2) a high level of collaboration is required to

identify and manage risks, 3) agility is essential to react quickly to unforeseen events and 4) the culture of risk management is a necessity. Characteristics such as agility, availability, efficiency, flexibility, redundancy, velocity and visibility were treated as secondary factors.

In parallel to the Cranfield studies, researchers at the Massachusetts Institute of Technology (MIT) analyzed many case studies of supply chain disruptions with a focus on identifying vulnerability characteristics and management responses such as flexibility, redundancy, security and collaboration (Sheffi 2005). It is critical to note that disruptions can also bring unexpected opportunities for success, as shown by three examples from Sheffi's work. First, the Los Angles Metrolink transit system increased its ridership by 20-fold immediately following the January 1994 Northridge earthquake. Second, FedEx seized opportunity in the aftermath of a strike at UPS in 1997 by filling unmet demand. Third, Dell took advantage of the West Coast port lockout in 2002 to spur demand for LCD monitors that they could ship economically via air freight, displacing bulkier CRTs. Such disruptions "can offer an opportunity to impress customers and win their loyalty" (Knemeyer, Corsi and Murphy 2003), and successful recovery and adaptation to new market forces can lead to competitive advantage (Rice and Caniato 2003). Definitions of resilience from the above studies and others are summarized in Table 2.2.

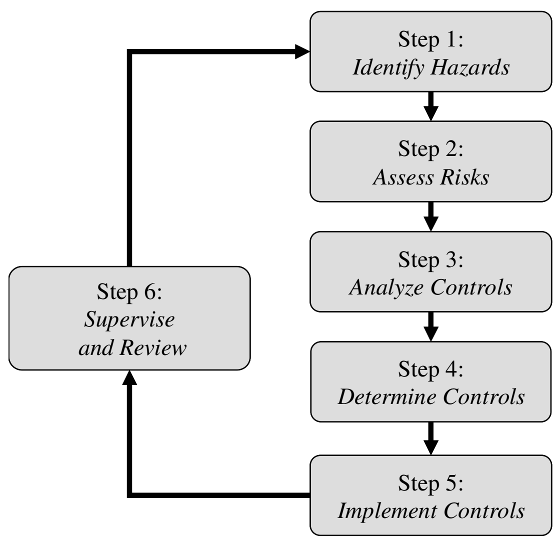
Source	Definition	Field of study
Merriam-Webster (2007)	Capability of a body to ***recover its size and shape*** after deformation	Engineering
Folke et al. (2004)	***Ability to rebound*** from a disturbance while maintaining diversity, integrity and ecological processes	Ecology
Gorman et al. (2005)	***Ability to bounce back*** from adversity	Psychology
Stoltz (2004)	***Ability to bounce back*** from adversity and ***move forward*** stronger than ever	Leadership
Rice and Caniato (2003)	***Ability to react*** to an unexpected disruption and ***restore normal operations***	Supply chain
Sheffi (2005)	***Containment of disruption*** and ***recovery*** from it	Supply chain
Christopher and Peck (2004a)	Ability of a system to ***return to its original state*** or ***move to a new, more desirable state*** after being disturbed	Supply chain
Fiksel (2006)	Capacity for complex industrial systems to ***survive, adapt and grow*** in the face of turbulent change	Supply chain

Table 2.2: Definitions of Resilience

Resilience versus Risk management

Resilience is an evolving concept and differs from traditional risk management. Since the 1970s, risk analysis techniques have played a major role in corporate decision making, especially when combined with financial models (Hertz and Thomas 1983). In practice, risk management entails examining all possible outcomes of a project or process, then weighing the potential returns against the potential risks of the investment (Carter 1972). Currently, the leading approach to Enterprise Risk Management comes from the Committee of Sponsoring Organizations of the Treadway Commission (COSO

2004). A typical view of the traditional risk management process is shown in Figure 2.1, depicting a continuous cycle of identification of hazards, assessment of risks, analysis of controls, choosing controls, implementing controls and review. In many applications, risks can be quantified based on historical data, but evaluating risks requires assumptions based on subjective information. Tang (2006a) reviews opportunities to integrate risk management techniques into a comprehensive supply chain risk management program: management of supply, products, demand and information. Applying this approach to each link in a global supply chain for every possible disruptive cause would be onerous.

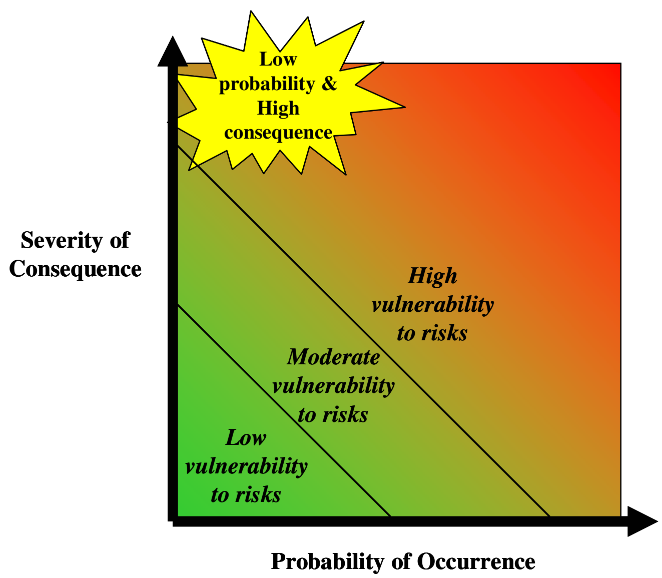


Adapted from: Manuele (2005).

Figure 2.1: Operational Risk Management Process

A critical step in the risk management process is risk assessment, illustrated in Figure 2.1, based on the assessed probability of an event and the estimated severity if the

event occurs. The greatest weakness of risk management is its inability to adequately characterize low-probability, high-consequence (LP/HC) events, upper-left corner of Figure 2.2 (Kunreuther 2006). Additionally, the traditional risk assessment approach cannot deal with unforeseeable events. We believe that the concept of supply chain resilience can fill these gaps and supplement existing risk management programs, thus enabling a supply chain to survive unforeseen disruptions and create competitive advantage.



Adapted from Manuele (2005).

Figure 2.2: Traditional Risk Assessment

DEVELOPMENT OF A CONCEPTUAL FRAMEWORK

Christopher and Peck (2004a) believe that a new priority has emerged for business planning: a higher degree of resilience. However, no existing study provides a

complete framework that encompasses the breadth of issues both internal and external to the supply chain. The following sections will describe our efforts to develop such a conceptual framework.

Model Development

We first assert two postulates that we accept as truths, by definition, to provide the necessary foundation in order to build on extant theory. These postulates will then lead to research propositions offered for future validation as the basis for implementation of the concept of resilience.

To begin, our resilience framework builds upon the basic concept of vulnerabilities. Supply chain disturbances can be internal or external, affecting products, services or resources, but all resulting from some type of change (Christopher and Peck 2004a). Thus, we adopt the following postulate:

POSTULATE 1: Forces of change create supply chain vulnerabilities.

Consistent with previous research (Svensson 2000, 2002, 2004; Chapman et al. 2002; Zsidisin 2003; Peck 2005; Sheffi 2005), we espouse the following definition of supply chain vulnerabilities: "*fundamental factors that make an enterprise susceptible to disruptions*." Our framework for resilience must take into account those fundamental factors which encompass the broadest possible range of disruptive threats.

Second, in order to counteract vulnerabilities, research has shown that a supply chain can develop capabilities that assure long-term survival. Capabilities are "*attributes required for performance or accomplishment*" (Merriam-Webster 2007). Literature suggests many different types of supply chain capabilities (Cranfield 2002, 2003; Hamal and Valikangas 2003; Rice and Caniato 2003; Fiksel 2003; Lee 2004; Peck 2005; Sheffi 2005). Concepts such as flexibility, agility, adaptability and visibility are just a few commonly discussed managerial capabilities. Thus, we adopt the following postulate:

POSTULATE 2: Management controls create supply chain capabilities.

We define supply chain capabilities as: "*attributes that enable an enterprise to anticipate and overcome disruptions*." These capabilities could prevent an actual disruption (e.g. security measures deterring a terrorist attack), mitigate the effects of a disruption (e.g. stock piles of emergency supplies) or enable adaptation following a disruption (e.g. development of new products or services, or entering a new market).

Tang (2006b) presents nine supply chain strategies that help a firm to excel under normal operations and recover quickly following disruptions: postponement, strategic stock, flexible supply base, make-and-buy, economic supply incentives, flexible transportation, revenue management, dynamic assortment planning and silent product rollover. Similarly, Lee (2004) presents methods to overcome both short- and long-term change based on three key capabilities: agility, adaptability and alignment. However, we believe that the scope of supply chain resilience requires a broader view than these

strategies; the framework should encompass all supply chain processes, relationships and resources that offer capabilities to overcome vulnerabilities. Herein is the essence of resilience, depicted in Figure 2.3 and stated in Proposition 1.

PROPOSITION 1: Supply chain resilience increases as capabilities increase and vulnerabilities decrease.

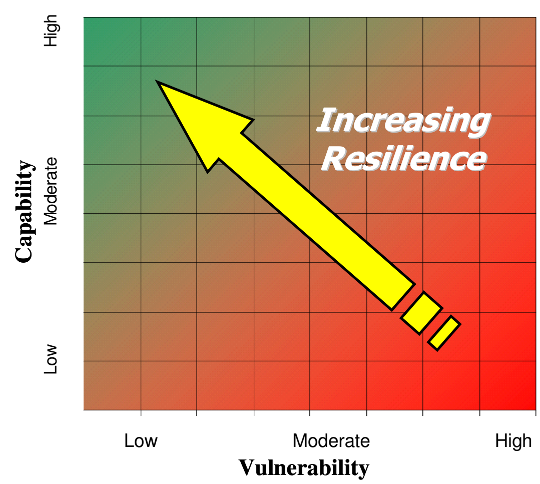


Figure 2.3: Measurement of Resilience

We believe that empirical studies can provide management insight into linkages between each vulnerability and a set of successfully employed capabilities to combat that vulnerability. For example, in the highly turbulent market of consumer electronics, a supply chain strategy of single or limited sourcing may be employed in order to achieve close collaboration and rapid time-to-market (Stank, Keller and Daugherty 2001;

Lambert and Knemeyer 2004). Alternatively, open-sourcing to multiple innovative suppliers may improve competitiveness in this volatile market (Christopher and Peck 2004a). Developing capabilities that are best linked to overcoming the supply chain's vulnerabilities create a state of balance between investment and risk. We define this state as "balanced resilience." Thus, we assert the following research proposition:

PROPOSITION 2: Linkages exist between each vulnerability and a specific set of capabilities that can directly improve balanced resilience.

However, as shown in Figure 2.4, a supply chain that does not develop sufficient capabilities to offset high levels of vulnerabilities will be overly exposed to risks. Conversely, a supply chain may over-invest in capabilities relative to their vulnerabilities and therefore erode profits. We assert that balanced resilience will result from a fit between the vulnerability factors and the capability factors, which is designated the Zone of Balanced Resilience in Figure 2.4. Thus, we advance the following research propositions:

PROPOSITION 3A: Excessive vulnerabilities relative to capabilities will result in excessive risk.

PROPOSITION 3B: Excessive capabilities relative to vulnerabilities will erode profitability.

PROPOSITION 3C: Supply chain performance improves when capabilities and vulnerabilities are more balanced.

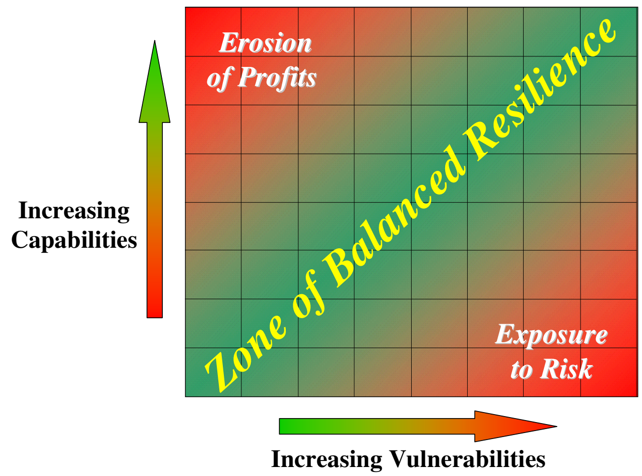


Figure 2.4: Resilience Fitness Space

Outside of the Zone of Balanced Resilience in either of the two unbalanced positions in accordance with Propositions 3A and 3B, it is expected that no firm can be viable in the long term as market forces will demand drastic change or drive the firm out of business. These concepts are summarized in the Supply Chain Resilience Framework, Figure 2.5, using the results of the three potential states of resilience described in Propositions 3A, 3B and 3C. Both potential states A and B are considered states of unbalanced resilience and are therefore undesirable. Only potential state C, obtained by the effective implementation of a portfolio of capabilities that is best matched with the supply chain's pattern of vulnerabilities will lead to improved performance, per Proposition 3C. We believe that through measurement of vulnerabilities and capabilities we can provide an evaluation of a supply chain's current level of resilience, and therefore, a tool to direct supply chain improvements.

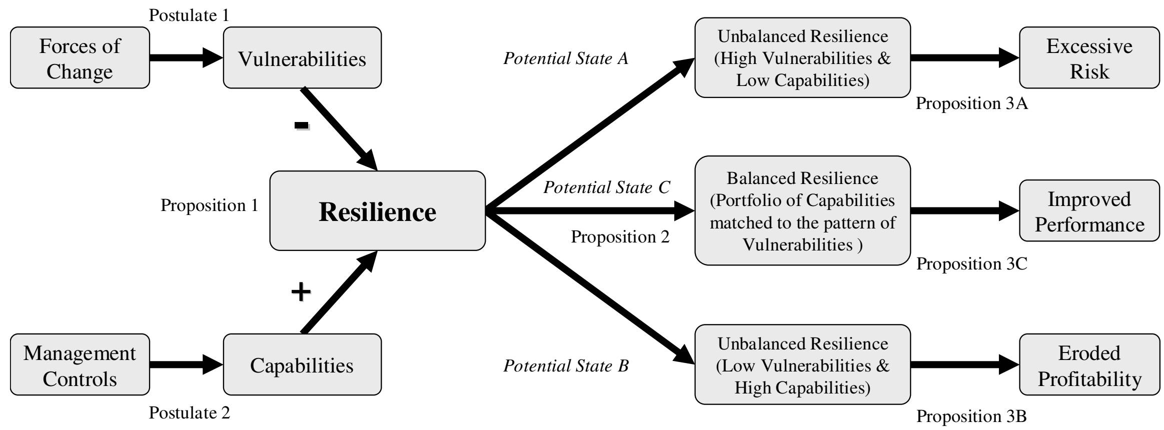


Figure 2.5: The Supply Chain Resilience Framework

Methodology and Validation

In order to implement the vulnerability and capability constructs of the Supply Chain Resilience Framework, detailed taxonomies of both constructs must be created. Using the tenets of Grounded Theory, theoretical structure was extended using empirical data in a systematic method (Glaser and Strauss 1967). Our initial taxonomies of resilience factors were first created based on extant literature, then refined and validated by supply chain managers at Limited Brands, Inc, an apparel and beauty care products retailer with a complex global supply chain. A second phase further explored the dimensions of resilience, in which focus groups were conducted at Limited Brands using a detailed interview protocol to spur open-ended discussions on recent supply chain disruptions among functional experts in order to extract the underlying vulnerabilities and capabilities.

Focus group research methodology was chosen for its ability to produce more in-depth information through interactive discussions (Goldman 1962). Although the literature shows that more costly individual interviews tend to produce a larger number of responses, focus groups are more effective for investigating complex topics and result in uncovering ideas that may have otherwise been overlooked by the subjects individually (Morgan 1996).

In all, eight separate focus groups were conducted at Limited Brands over a period of two months, with each group having two to four members of similar backgrounds to encourage more in-depth discussions. Following an open discussion of members' recent experiences with supply chain disruptions, the refined Supply Chain Resilience taxonomy was presented, and subjects were asked to match their experiences to the framework. This process was effective in identifying gaps and redundancies without biasing the group members' opinions. A total of 50 examples of disruption vulnerabilities and an additional 96 specific capabilities were recorded during this process, see Figures 2.6 and 2.7.

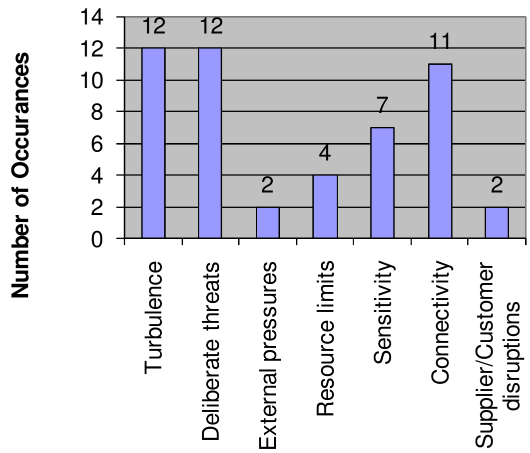
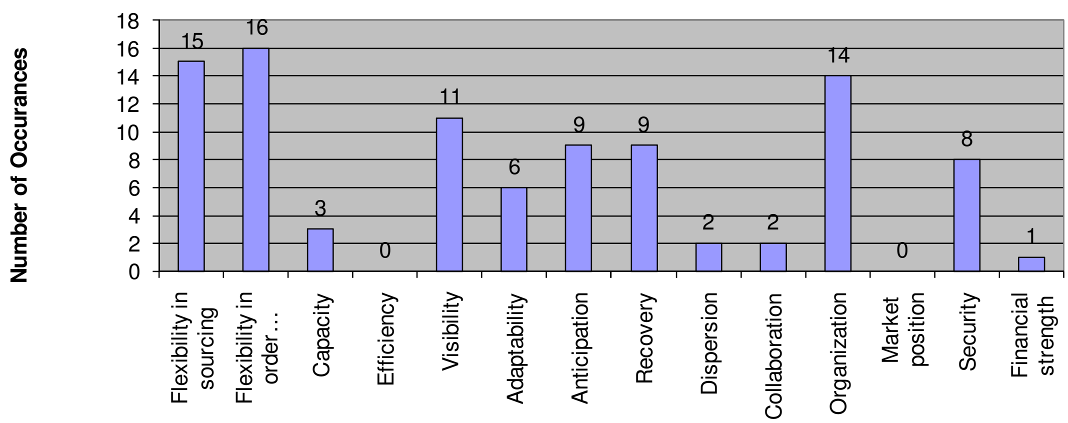


Figure 2.6: Vulnerability Examples from Focus Groups



Note: While refining the Supply Chain Resilience Framework, it was noted that Limited Brands outsources production and, therefore, had no examples of internal production efficiency capabilities. In addition, the focus groups had no participation from sales or marketing representatives who would be expected to have greater insight into Market position capabilities; however, both of these capabilities are well documented in literature and were validated by senior management at Limited Brands.

Figure 2.7: Capability Examples from Focus Groups

Successive iterations of the Supply Chain Resilience taxonomy were presented to each of the eight focus groups until no further updates were found, thus meeting goals for saturation of ideas and convergence of propositions (Patton 1990). Additionally, by treating each focus group as an individual case study of the members' experiences, the study also meets the recommended minimums of six to ten cases for providing compelling evidence to support the initial propositions (Ellram 1996; Yin 2003). The resulting taxonomy was presented to the sponsoring senior management at Limited Brands for a final round of validation. A consensus was achieved between the research team and the management panel in terms of the breadth, depth and clarity of the Supply Chain Resilience Framework. Table 2.3 defines the final seven vulnerability factors. However, in order to translate the vulnerability factors into measurable attributes, each factor was refined during this research resulting in 40 specific vulnerability sub-factors. Table 2.4 includes the entire vulnerability taxonomy with sub-factors matched with a select sample from literature. Table 2.5 lists the final 14 capability factors, with their 71 sub-factors listed in Table 2.6. This compilation provides the first detailed taxonomy of supply chain resilience, allowing management to develop a portfolio of capabilities balancing their inherent pattern of vulnerabilities, in accordance with the Supply Chain Resilience Framework.

Vulnerability Factor	Definition	Sub-Factors
Turbulence	Environment characterized by frequent changes in external factors beyond your control	Natural disasters, Geopolitical disruptions, Unpredictability of demand, Fluctuations in currencies and prices, Technology failures, Pandemic
Deliberate threats	Intentional attacks aimed at disrupting operations or causing human or financial harm	Theft, Terrorism/sabotage, Labor disputes, Espionage, Special interest groups, Product liability
External pressures	Influences, not specifically targeting the firm, that create business constraints or barriers	Competitive innovation, Social/Cultural change, Political/Regulatory change, Price pressures, Corporate responsibility, Environmental change
Resource limits	Constraints on output based on availability of the factors of production	Supplier, Production and Distribution capacity, Raw material and Utilities availability, Human resources
Sensitivity	Importance of carefully controlled conditions for product and process integrity	Complexity, Product purity, Restricted materials, Fragility, Reliability of equipment, Safety hazards, Visibility to stakeholders, Symbolic profile of brand, Concentration of capacity
Connectivity	Degree of interdependence and reliance on outside entities	Scale of network, Reliance upon information, Degree of outsourcing, Import and Export channels, Reliance upon specialty sources
Supplier/Customer disruptions	Susceptibility of suppliers and customers to external forces or disruptions	Supplier reliability, Customer disruptions

Table 2.3: Vulnerability Factors

Main Factors of Vulnerability	Descriptors	Svensson (2000)	Hamel and Valikangas (2003)	Christopher, Rutherford (2004)	Peck (2005)	Sheffi (2005)
Turbulence	Natural disasters	X		X	X	X
	Exposure to geopolitical disruptions		X		X	X
	Unpredictability of demand	X	X		X	X
	Fluctuations in currencies & prices					
	Unforeseen technology failures					
	Pandemic					
Deliberate threats	Piracy & theft			X	X	X
	Terrorism & sabotage				X	X
	Labor disputes	X			X	X
	Industrial espionage					
	Special interest groups					
	Product liability					
External pressures	Innovation (competition)		X		X	
	Social/Cultural changes				X	
	Political/Regulatory changes		X		X	
	Price pressures (competition)					
	Corporate responsibility					
	Environmental changes					
Resource limits	Supplier capacity					
	Production capacity					
	Distribution capacity					
	Raw material availability					
	Utilities availability					
	Human resources					
Sensitivity	Complexity			X	X	X
	Product purity					
	Restricted materials					
	Fragility					
	Reliability of equipment				X	
	Potential safety hazards					
	Visibility of disruption to stakeholders					
	Symbolic profile of brand					
	Concentration of capacity					
Connectivity	Scale/Extent of supply network	X			X	X
	Reliance upon information flow	X	X		X	X
	Degree of outsourcing				X	X
	Import/Export channels					
	Reliance upon specialty sources					
Supplier/Customer disruptions	Supplier trust, loyalty, relations, reliability	X			X	X
	Customer disruptions					

Table 2.4: Supply Chain Resilience Framework — Vulnerabilities

Capability Factor	**Definition**	**Sub-Factors**
Flexibility in sourcing	Ability to quickly change inputs or the mode of receiving inputs	Part commonality, Modular product design, Multiple uses, Supplier contract flexibility, Multiple sources
Flexibility in order fulfillment	Ability to quickly change outputs or the mode of delivering outputs	Alternate distribution channels, Risk pooling/sharing, Multi-sourcing, Delayed commitment/Production postponement, Inventory management, Re-routing of requirements
Capacity	Availability of assets to enable sustained production levels	Reserve capacity, Redundancy, Backup energy sources and communications
Efficiency	Capability to produce outputs with minimum resource requirements	Waste elimination, Labor productivity, Asset utilization, Product variability reduction, Failure prevention
Visibility	Knowledge of the status of operating assets and the environment	Business intelligence gathering, Information technology, Product, equipment and people visibility, Information exchange
Adaptability	Ability to modify operations in response to challenges or opportunities	Fast re-routing of requirements, Lead time reduction, Strategic gaming and simulation, Seizing advantage from disruptions, Alternative technology development, Learning from experience
Anticipation	Ability to discern potential future events or situations	Monitoring early warning signals, Forecasting, Deviation and near-miss analysis, Risk management, Business continuity/preparedness planning, Recognition of opportunities
Recovery	Ability to return to normal operational state rapidly	Crisis management, Resource mobilization, Communications strategy, Consequence mitigation
Dispersion	Broad distribution or decentralization of assets	Distributed decision-making and Assets, Decentralization of key resources, Location-specific empowerment, Dispersion of markets
Collaboration	Ability to work effectively with other entities for mutual benefit	Collaborative forecasting, Customer management, Communications, Postponement of orders, Product life cycle management, Risk sharing with partners
Organization	Human resource structures, policies, skills and culture	Accountability, Creative problem solving, Cross-training, Substitute leadership/empowerment, Learning/benchmarking, Culture of caring
Market position	Status of a company or its products in specific markets	Product differentiation, Customer loyalty/retention Market share, Brand equity, Customer relationships, Customer communications
Security	Defense against deliberate intrusion or attack	Layered defenses, Access restrictions, Employee involvement, Collaboration with governments, Cyber-security, Personnel security
Financial strength	Capacity to absorb fluctuations in cash flow	Insurance, Portfolio diversification, Financial reserves and liquidity, Price margin

Table 2.5: Capability Factors

Main Factors of Capability	Descriptors	Cranfield (2002, 2003)	Hamel and Valikangas (2003)	Rice and Caniato (2003)	Fiksel (2003)	Peck (2005)	Sheffi (2005)	Tang (2006b)
Flexibility-sourcing	Commonality (facilities, processes)						X	
	Product commonality (modularity, interchangeability)			X			X	X
	Multiple uses for supplies			X			X	X
	Supplier contract flexibility	X	X	X	X	X	X	X
	Multiple sources	X	X	X	X	X	X	X
Flexibility-fulfillment	Alternate distribution channels		X	X		X		X
	Risk pooling/sharing						X	
	Multi-sourcing (peak vs. base)							
	Delayed commitment, Production postponement						X	X
	Inventory management							
	Fast re-routing of requirements							
Capacity	Reserve capacity (materials, assets, labor, inventory)	X		X		X	X	X
	Redundancy (assets, labor)	X		X			X	
	Backup energy sources/communications						X	
Efficiency	Waste elimination	X			X		X	
	Labor productivity							
	Asset utilization							
	Product variability reduction							
	Failure prevention							
Visibility	Business intelligence gathering	X					X	
	Information technology	X		X		X		
	Products, Assets, People visibility	X		X		X		
	Collaborative information exchange							

Continued

Table 2.6: Supply Chain Resilience Framework — Capabilities

Table 2.6 continued

Main Factors of Capability	Descriptors	Cranfield (2002, 2003)	Hamel and Valikangas (2003)	Rice and Caniato (2003)	Fiksel (2003)	Peck (2005)	Sheffi (2005)	Tang (2006b)
Adaptability	Fast re-routing of requirements			X			X	X
	Process Improvement, Lead time reduction	X		X	X	X	X	X
	Strategic gaming & simulation				X	X	X	
	Seizing advantage from disruptions						X	
	Alternative technology development				X	X		
	Learning from experience, Reengineering					X	X	X
Anticipation	Monitoring early warning signals			X		X	X	
	Forecasting	X				X	X	
	Deviation, Near-miss analysis					X	X	
	Contingency planning, Preparedness (Training/Drill/Exercise plans)			X			X	
	Risk management, Business continuity planning	X		X	X		X	X
	Recognition of opportunities						X	
Recovery	Crisis management	X		X			X	X
	Resource mobilization							
	Communications strategy							
	Consequence mitigation							
Dispersion	Distributed decision-making				X		X	
	Distributed capacity & assets	X	X	X	X		X	X
	Decentralization of key resources (including data)				X		X	
	Location-specific empowerment							
	Geographic dispersion of markets							
Collaboration	Collaborative forecasting, Customer relationship management	X	X	X	X	X	X	X
	Communications - internal, external	X			X	X	X	
	Postponement of orders							
	Product life cycle management							
	Risk sharing with partners							

Continued

Table 2.6 continued

Main Factors of Capability	Descriptors	Cranfield (2002, 2003)	Hamel and Valikangas (2003)	Rice and Caniato (2003)	Fiksel (2003)	Peck (2005)	Sheffi (2005)	Tang (2006b)
Organization	Learning, Benchmarking, Feedback			X				
	Responsibility, Accountability & Empowerment	X						
	Teamwork, Creative problem solving	X	X				X	
	Training, Cross-train workers			X			X	
	Substitute leadership capacity							
	Culture of caring for employees							
Market position	Product differentiation		X					
	Customer loyalty/retention							
	Market share							
	Brand equity							
	Customer relationships							
	Customer communications							
Security	Layered defenses	X		*		X	X	
	Access restriction	X					X	
	Employee involvement in security						X	X
	Collaboration with governments	X				X	X	
	Cyber-security						X	X
	Personnel security							
Financial strength	Insurance			X				
	Portfolio diversification		X		X			X
	Financial reserves & liquidity		X		X			X
	Price margin							

* NOTE: Authors specifically describe security as separate from resilience.

MANAGERIAL IMPLICATIONS

The Supply Chain Resilience Framework has potential for providing management insight into their firm's strengths, weaknesses and priorities. First, by identifying highly rated capabilities, managers will have detailed information on their strengths. In line with the resource-based approach to strategy analysis (Grant 1991), firms must first

identify their current resources and strengths – what they can do more effectively than their rivals. However, Proposition 3C states that resilience is not simply a matter of strengths, but it is the balance between capabilities and vulnerabilities that creates a firm's true competitive advantage. For example, one global electronics firm reported very strong security programs, but they may be eroding profits as the supply chain does not face significant vulnerabilities from Deliberate threats, per Proposition 3B. A global supply chain will have high levels of Connectivity by design and, for example, must create strong capabilities in the areas of Collaboration, Visibility and Flexibility in order fulfillment to effectively manage their vast number of interrelated operations between multiple tiers of suppliers and customers, thus contributing to balanced resilience.

Second, the framework can identify weaknesses in the network of firms that comprise the supply chain. Low capabilities that correspond to moderate or high vulnerabilities can dramatically degrade the supply chain's resilience. For example, a supply chain with a high vulnerability to Connectivity can face disastrous consequences if it has poor capabilities of Visibility and Collaboration, per Proposition 3A.

Finally, the framework provides managerial guidance for setting priorities to create a strategy for improving Supply Chain Resilience. This strategy must be based on assessment of the firm's pattern of vulnerabilities and its competitive advantages, weighed against the potential return on investment. In doing so, corporate strategy will focus resource investments to fill gaps (Grant 1991). For example, if a high vulnerability of the symbolic profile of the brand can directly threaten a firm, a high priority should be placed on investments in product quality assurance (see Proposition 2). A well-managed

enterprise continually examines its turbulent environment and realigns its resources faster than its rivals (Hamel and Valikangas 2003; Lummus, Duclos and Vokurka 2003). Therefore, periodic assessment of the resilience of the supply chain is necessary.

CONTRIBUTIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The concept of resilience is broader in scope than integrated supply chain management, continuity planning, risk management or an amalgamation of all of these disciplines (Peck 2005). The Supply Chain Resilience Framework is the first to define resilience in terms of measurable variables. This conceptual study offers three major contributions. First, the framework recognizes the need to balance managerial capabilities with the inherent vulnerabilities of the supply chain design and the environment in which it operates. Second, through our detailed review of literature and exploratory research, we have identified 14 unique capabilities which contribute to increasing a supply chain's level of resilience. By developing the taxonomy (Table 2.6), measurable capability sub-factors have been identified. However, as stated in Proposition 3C, we believe that the best level of resilience will be achieved only when a balance is maintained between capabilities and vulnerabilities. Therefore, this research consolidated a wide range of literature on supply chain disruptions to identify seven distinct supply chain vulnerabilities (Table 2.4). Thus, the third contribution of this research was to translate resilience concepts into the Supply Chain Resilience Framework (Figure 2.5) to create a useful managerial tool for improving performance.

This exploratory research must be followed by empirical validation. Feedback to date from Limited Brands and other firms has been very positive and suggests great potential for the Supply Chain Resilience Framework. Empirical evaluation of the resilience definitions and concepts presented here is required by academics and practitioners to provide validation. Large-scale testing will be required to confirm propositions. Future research must engage a wide range of functional specialists and process integration experts to capture the cross-functional interactions of capabilities. In addition, detailed analysis of past disruptions and successful anticipation, recovery and adaptation efforts will be essential in future research to determine the significant linkages between specific capabilities and inherent vulnerabilities, as stated in Proposition 2. Finally, further research is required to address measurement and implementation issues in order to convert this conceptual framework into a successful managerial tool.

History has proven over the past two centuries that America as a nation is "far more resilient than the companies it has spawned" (Hamel and Valikangas 2003). Yet even after wide-reaching disruptive events such as 9/11 and Hurricane Katrina, an MIT study found that "most companies are still not thinking systematically about managing supply chain risks and vulnerabilities" (Sheffi 2005). Our Supply Chain Resilience Framework will provide a new tool to assess supply chain fitness and provide critical insights for decision making. Business leaders must demand resilience measures in order to manage today's increasingly complex supply chains (Ahlquist et al. 2003).

Just as the market is constantly changing, threats to our supply chains are evolving, adapting and changing as well. Resilience is not a static goal but requires our

continuing attention (Allenby and Fink 2005). "These are challenging times but…there are ways in which companies can create more resilient supply chains" (Christopher and Peck 2004b). Resilience is a mandatory characteristic of a supply chain in order to survive in the short term, but also provides the ability to adapt to change and thrive in the long term. Management strategists are beginning to argue that supply chain resilience will prove to be the ultimate competitive advantage in an age of turbulence (Hamel and Valikangas 2003).

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CHAPTER 3

CREATION AND VALIDATION OF A RESILIENCE ASSESSMENT TOOL

INTRODUCTION

The complexity of supply chains is growing and the turbulence they experience is increasing. Business leaders need a method to manage change in their complex supply chains, and the concept of resilience now provides a context for accomplishing this goal. This chapter presents a tool that supply chain leaders will need to assess their current level of resilience and to guide purposeful change in order to ensure their supply chain can survive, adapt and grow in the complex unknowns of the future.

Complexity is difficult to manage (Mason 2006) and is driven by the increasing number of elements, interactions that are non-linear with small perturbations causing severe impacts, dynamics of the systems as systems have a history but their hindsight does not lead to foresight because their systems and external conditions constantly change (Snowden and Boone 2007). Even rare events are likely to disrupt a link somehow, somewhere, given the complexity of modern supply chains (Sheffi 2005). Compounding the complexity of today's supply chains is the severe impact of disruptions. Hendricks and Singhal (2005) found that over the period from one year

before through two years after a disruption is announced, stockholders found their stock prices down nearly 40 percent, with the average effect in the year leading to the public announcement of a disruption is a 107 percent drop in operating income. Conventional risk-management approaches, as those designed to deal with previously experienced incidents such as floods or scandals, don't always work. Strategies to deal with change need to be purposely aligned with a company's earning drivers (Ahlquist et al. 2003). Firms need to balance revenue streams with preparation and recovery costs, short-term customer service and long-term supply chain value in terms of return on assets (Slone, Mentzer and Dittmann 2007). Debra van Opstal, President of the Council on Competitiveness, agrees that "managing this rapidly changing risk landscape is an emerging competitive challenge" and meeting that challenge demands resilience (Council on Competitiveness 2007). The Supply Chain Resilience Framework (Pettit, Fiksel and Croxton 2008) identifies the sources of change in seven categories of vulnerabilities: Turbulence, Deliberate threats, External pressures, Resource limits, Sensitivity, Connectivity and Supplier/Customer disruptions. These vulnerabilities must be counter-balanced with managerial controls that create supply chain capabilities: Flexibility in sourcing, Flexibility in order fulfillment, Capacity, Efficiency, Visibility, Adaptability, Anticipation, Recovery, Dispersion, Collaboration, Organization, Market position, Security and Financial strength. Combined, both the vulnerabilities and the capabilities must therefore be measured in order to assess the current level of resilience, which is the goal of this chapter.

This research follows the conceptual foundations of Pettit, Fiksel and Croxton (2008) to create a measurement instrument in order to implement the Supply Chain Resilience Framework, thus providing direction for a supply chain to improve its resilience. This chapter begins with a literature review, followed by the methodology to create and validate the assessment and concludes with results and recommendations from initial application of the instrument with seven global manufacturing supply chains.

LITERATURE REVIEW

Background

Supply chain resilience derives from the foundations of ecology (Folke et al. 2002, 2004; Perrings 2006), psychology (Bonanno 2004; Gorman et al. 2005), sociology (Adger 2000), risk management (Starr, Newfrock and Delurey 2003) and network theory (Callaway et al. 2000). Following a series of major disruptive events in global economies, several in-depth studies were conducted to better understand how supply chains can more effectively adapt to change (Cranfield University 2002, 2003; Sheffi 2005). As the term resilience entered the business vocabulary, researchers addressed components that contribute to supply chain disruptions and components that assist enterprises in preventing and coping with those disruptions (Hamel and Valikangas 2003; Rice and Caniato 2003; Christopher and Peck 2004; Kleindorfer and Saad 2005; Tang 2006b). As these varying viewpoints intersect with the domain of traditional risk management's role in identifying and reducing threats (COSO 2004; Tang 2006a; Manuj and Mentzer 2008), the concept of resilience began to supplement the analytical

techniques with strategies that do not require exact quantification, complete enumeration of possibilities or assumptions of a representative future (Pettit, Fiksel and Croxton 2008). Strategic imperatives call for supply chains to be less brittle and more adaptive to change through: 1) supply chain design, 2) focus on business process management to enhance capabilities across the supply chain, 3) visibility to demand and supply throughout the supply chain, 4) supplier relationship management and 5) infusing a culture of resilience (Wisdomnet 2006). With operational risk rated as the most important risk that executives face today, increasing economic value through better risk-based decision making was viewed as the top imperative (Towers-Perrin 2006). Therefore, resilience must become a strategic vision for leadership (Council on Competitiveness 2007). Any organization that hopes to become resilient must address four challenges: the cognitive challenge, the strategic challenge, the political challenge and the ideological challenge (Hamel and Valikangas 2003). The breadth of these challenges leads to the necessity of an enterprise-wide view of the firm as encompassed in the Supply Chain Resilience Framework. Combined with the integration of resilient supply chain partners, firms must develop a resilient supply chain in order to survive.

However, Pettit, Fiksel and Croxton (2008) identified a lack of consensus on the definition of supply chain resilience and a research gap in linking the threats to operations and the strategies to overcome them. Based on the foundations in life and social sciences, resilience was defined by Fiksel (2006) and adapted by the Council on Competitiveness (2007) as “the capacity for an enterprise to survive, adapt and grow in the face of turbulent change.” Then, through a broad literature search combined with

focus group research conducted in collaboration with Limited Brands, Inc., a leading apparel and beauty care products company, resilience was proposed to consist of two constructs: Vulnerabilities – *fundamental factors that make an enterprise susceptible to disruptions* and Capabilities – *attributes that enable an enterprise to anticipate and overcome disruptions* (Pettit, Fiksel and Croxton 2008). These constructs were refined to compose 21 factors comprised of 111 sub-factors, see Tables 3.1 and 3.2. The authors propose that assessment of these 21 factors can be used to evaluate a supply chain's current state of resilience, and therefore, through strategic review of the resilience fitness space, see Figure 3.1, recommendations for resilience improvements can be prioritized to meet corporate goals. The following sections define resilience variables based on work from Chapter 2 and expound on these factors that comprise the construct of resilience.

Vulnerability Factor	Definition	Sub-Factors
Turbulence	Environment characterized by frequent changes in external factors beyond your control	Natural disasters, Geopolitical disruptions, Unpredictability of demand, Fluctuations in currencies and prices, Technology failures, Pandemic
Deliberate threats	Intentional attacks aimed at disrupting operations or causing human or financial harm	Theft, Terrorism/sabotage, Labor disputes, Espionage, Special interest groups, Product liability
External pressures	Influences, not specifically targeting the firm, that create business constraints or barriers	Competitive innovation, Social/Cultural change, Political/Regulatory change, Price pressures, Corporate responsibility, Environmental change
Resource limits	Constraints on output based on availability of the factors of production	Supplier, Production and Distribution capacity, Raw material and Utilities availability, Human resources
Sensitivity	Importance of carefully controlled conditions for product and process integrity	Complexity, Product purity, Restricted materials, Fragility, Reliability of equipment, Safety hazards, Visibility to stakeholders, Symbolic profile of brand, Concentration of capacity
Connectivity	Degree of interdependence and reliance on outside entities	Scale of network, Reliance upon information, Degree of outsourcing, Import and Export channels, Reliance upon specialty sources
Supplier/Customer disruptions	Susceptibility of suppliers and customers to external forces or disruptions	Supplier reliability, Customer disruptions

Table 3.1: Vulnerability Factors ***(re: Table 2.3)***

Capability Factor	Definition	Sub-Factors
Flexibility in Sourcing	Ability to quickly change inputs or the mode of receiving inputs	Part commonality, Modular product design, Multiple uses, Supplier contract flexibility, Multiple sources
Flexibility in Order Fulfillment	Ability to quickly change outputs or the mode of delivering outputs	Alternate distribution channels, Risk pooling/sharing, Multi-sourcing, Delayed commitment/Production postponement, Inventory management, Re-routing of requirements
Capacity	Availability of assets to enable sustained production levels	Reserve capacity, Redundancy, Backup energy sources and communications
Efficiency	Capability to produce outputs with minimum resource requirements	Waste elimination, Labor productivity, Asset utilization, Product variability reduction, Failure prevention
Visibility	Knowledge of the status of operating assets and the environment	Business intelligence gathering, Information technology, Product, equipment and people visibility, Information exchange
Adaptability	Ability to modify operations in response to challenges or opportunities	Fast re-routing of requirements, Lead time reduction, Strategic gaming and simulation, Seizing advantage from disruptions, Alternative technology development, Learning from experience
Anticipation	Ability to discern potential future events or situations	Monitoring early warning signals, Forecasting, Deviation and near-miss analysis, Risk management, Business continuity/preparedness planning, Recognition of opportunities
Recovery	Ability to return to normal operational state rapidly	Crisis management, Resource mobilization, Communications strategy, Consequence mitigation
Dispersion	Broad distribution or decentralization of assets	Distributed decision-making and Assets, Decentralization of key resources, Location-specific empowerment, Dispersion of markets
Collaboration	Ability to work effectively with other entities for mutual benefit	Collaborative forecasting, Customer management, Communications, Postponement of orders, Product life cycle management, Risk sharing with partners
Organization	Human resource structures, policies, skills and culture	Accountability, Creative problem solving, Cross-training, Substitute leadership/empowerment, Learning/benchmarking, Culture of caring
Market position	Status of a company or its products in specific markets	Product differentiation, Customer loyalty/retention Market share, Brand equity, Customer relationships, Customer communications
Security	Defense against deliberate intrusion or attack	Layered defenses, Access restrictions, Employee involvement, Collaboration with governments, Cyber-security, Personnel security
Financial strength	Capacity to absorb fluctuations in cash flow	Insurance, Portfolio diversification, Financial reserves and liquidity, Price margin

Table 3.2: Capability Factors ***(re: Table 2.5)***

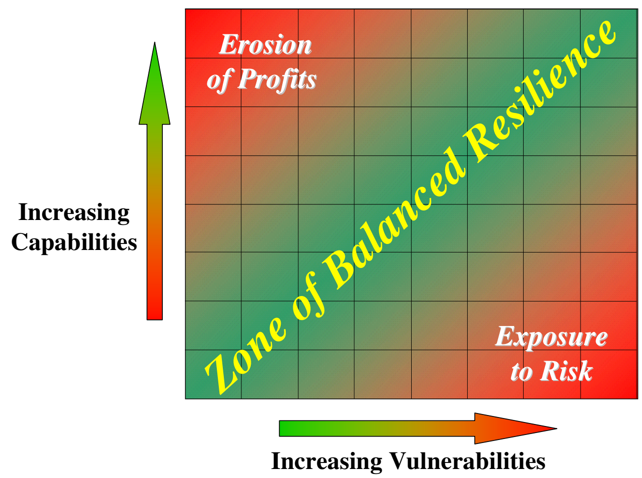


Figure 3.1: Resilience Fitness Space ***(re: Figure 2.4)***

Vulnerabilities

Until recently, the concept of supply chain vulnerability has been unexplored and its meaning was ambiguous (Svensson 2000). Svensson (2002) defines supply chain vulnerability as unexpected deviations from the norm and their negative consequences. A similar perspective is that vulnerability can be viewed as a combination of the likelihood of an event and its potential severity (Sheffi 2005; Craighead et al. 2007). Both these definitions have foundations from traditional risk management techniques and are expanded by other authors (Chapman et al. 2002; Zsidisin 2003; Svensson 2004; Peck 2005). Taking a broad view of vulnerability, we attempt to encompass all sources of change, "fundamental factors that make an enterprise susceptible to disruptions" (Pettit, Fiksel and Croxton 2008). Initial studies evaluating real-life disruptions in a global manufacturing supply chain revealed seven unique categories of vulnerabilities: Turbulence, Deliberate threats, Resource limits, Sensitivity, Connectivity and

Supplier/Customer disruptions (Pettit, Fiksel and Croxton, 2008). The following sections define these factors as empirically developed in Chapter 2 and provide greater detail to their components.

Turbulence

Turbulence is an environment characterized by frequent changes in external factors beyond your control, as when outcomes change frequently, profoundly and in ways that are difficult to predict (Siggelkow and Rivinkin 2005). Sub-factors of turbulence are categorized by changes in demand, prices, politics, nature, technology and health. First, unpredictability in customer demand can cause both positive change such as increased sales and negative change such as decreased sales or variability in sales (Eisenhardt and Brown 1998; Gryskiewicz 2005; Mason 2006). Although sales are made to your customer, a supply chain's final downstream point is the end consumer (assuming no reverse-flow nodes for recovery or final nodes for disposal). Consumer demand is typically the primary source of the unpredictability; however, significant fluctuations can be caused within the supply chain as in the bullwhip effect, the phenomenon first identified by Forrester's work (1958) with the term later coined by Sterman (1989) (see also Lee, Padmanabhan and Whang 1997).

Turbulence can also come from price fluctuations, including interest rate volatility (Pettit and Robb 1996) and global currency exchange rate fluctuations, which are both based on global macroeconomic forces. Other global forces directly affect a supply chain, such as geopolitical shocks that create significant, unexpected disruptions.

Socialization of assets, labor laws, import/export tariffs, quotas and barriers can slow or even halt trade, potentially dissolving corporations (Hamal and Valikangas 2003; Peck 2005; Sheffi 2005).

Probably the most widely studied turbulence causes are natural disasters such as hurricanes, floods, earthquakes and the like (Svensson 2000; Christopher and Rutherford 2004; Sheffi 2005). However, another form of turbulence is created when our technology fails unexpectedly. And finally, Health and Human Services officials recently testified on potential for an avian flu epidemic, which experts fear could prompt the next world pandemic if it develops the ability to spread easily between humans (AHS News 2005). Major health disasters can create severe turbulence by effecting consumer demand or directly impacting a supply chain's labor resources.

Deliberate Threats

Deliberate threats are intentional attacks aimed at disrupting operations or causing human or financial harm. A variety of threats are posed to supply chains: terrorism, theft, unions, special interest groups, industrial espionage and product liability claims. Although not directly targeting a specific firm, the morning of September 11th, 2001, made the world once again aware of the threats from terrorism. These attacks are typically political in nature, and even if a firm or its supply chain is not harmed directly, the ramifications from government reactions, infrastructure damage, network congestion or public response can be significant (Sheffi 2001). With supply chains reaching globally, "the danger has never been greater than it is today because of global terrorism,

which has landed workplaces all over the world in the middle of a war zone" (Mitroff and Alpaslan 2003).

Similarly, piracy and theft can attack a supply chain at any link. Attacks in this category are motivated not by the desire for corporate gain or to create an economic advantage, these criminal attacks are for personal gain. For example, a shipment of Intel chips was easily identified by the label "Intel Inside" – a very expensive loss at $5 million (Sheffi 2005). Since the industrial revolution, labor unions have also been a major threat, with positive advantages as well, with sporadic but sometimes dramatic confrontations between management and labor. The 2002 International Longshore and Warehouse Union lock-out (Tirschwell 2002) and an 8-hour work stoppage in 2008 in protest against the war in Iraq (Mongelluzzo 2008) deliberately affected a vast number of importers and exporters.

Special interest groups have also used the power of massing together for a common cause. From civil rights to environmental concerns, these groups can wield significant power through the media, consumers and government.

Industrial espionage, in contrast to terrorism, is defined as intentional attempts to unlawfully subvert a competitor or gain a competitive advantage for commercial purposes. Intellectual property such as product design and formulations are typical targets of industrial espionage. Companies are made more vulnerable through cyber crimes with the advancement of digital data storage and legal dissemination between partners.

And finally, product liability is a threat to all firms. However, aggressive programs of product safety and liability prevention not only help reduce accidents and increase safety, they also ultimately can result in more competitive products (Terzich 2005).

External Pressures

External pressures are influences, not specifically targeting the firm, that create business constraints or barriers. Categories of external pressures are competitive innovation, government regulations, price pressures, corporate responsibility, social/cultural changes and environmental changes. First, competitive innovation pressures stem from the desire of other firms to create advantages for themselves in the market. The first to launch a new, innovative product will capture market share and typically command higher price margins. The race is to maintain or recover competitive product offerings. When a major technological innovation is launched, "a wave of new firms implement the innovation and enter the market" if it is economically feasible (Wang 2007).

Government regulations provide a legal framework for business operations, while providing safeguards such as property rights and security services. However, in imposing the interests of society, government regulations can pose significant external pressures by enforcing limitations and adding expenses to operations. For example, during the outbreak of Foot and Mouth Disease in England in 2001, the government reacted quickly and by the third day banned all transportation of livestock and ordered the destruction of

the originally infected herds (Poortinga et al. 2004). In addition to quickly expanding the radius of quarantine, all travel was curtailed in areas of the countryside in attempts to limit the spread of the disease. The result was a significant drop in tourism and trade that caused more economic damage than the Foot and Mouth Disease caused to agriculture (Sheffi 2005). Customs, quotas and tariffs are other examples of government regulations that restrict trade and add time and cost to the transportation of goods.

Next, price pressures are some of the strongest market forces. Global labor rates are a major factor in locating production. Competitors may offer the same or similar products or services at discounted prices, either to gain short-term sales in order to increase market share or as part of a long-term competitive strategy. Southwest Airlines, in offering no-frills service with a standardized fleet of aircraft, short on-the-ground turn-around and an in-house reservation system dramatically reduced prices in the markets they serve.

Corporate responsibility is not new, but has garnered more public interest in recent years. Today, even the social and environmental standards of suppliers must be considered (Wright, Smith and Wright 2007). For example, Nike faced significant pressure from consumers due to the working conditions of suppliers in Indonesia (Bernstein, Shari and Malkin 2000).

Social and cultural changes are typically exerted through slow changes that occur over long periods of time. Consumer preference for style and needs change at various rates. In the extreme, the urbanization of population has effected market locations and

demands, and anti-smoking campaigns in the United States have resulted in dramatic decrease in demand.

Climate change also affects our use of resources, along with the interrelated social and governmental pressures to reduce emissions and waste to ensure a sustainable ecosystem for society. The "Green" movement has already changed consumer preferences for many material selections and greater efficiency of equipment operation (Hoffman 2005).

Resource Limits

Resource limits are constraints on output based on availability of the factors of production. Sub-factors include supplier capacity, production capacity, distribution capacity, raw material availability, utilities availability and human resources availability. These combine to create all the necessary factors of production. First, suppliers provide the materials and components that are sourced from outside of the focal firm. Suppliers must have the necessary production capacity to meet a firm's baseline and surge demands, even during periods of industry spikes where a supplier may have multiple customers surging orders simultaneously. Typically, during such an event a supplier will ration available assets to all customers based on fair-share quotas or other contractual obligations. Using multiple suppliers, even spreading them out over multiple continents, is one strategy to obtain sufficient supplier capacity (Economist 2006).

Internal production capacity is a capital investment decision by the firm that can also create resource limits. Due to long lead-times for equipment acquisition and facility

construction, these are strategic and potentially disastrous decisions if forecasted demand is significantly less than or exceeds predictions. Evaluation of asset utilization is important in computing usable capacity where changes in production runs (i.e. more set-up changes than planned) or unscheduled maintenance downtime is required. This can be extremely costly following harsh implementation of lean tenets where managers reduce excess capacity as purely waste. These firms become fragile, "that is, without buffers in the form of extra capacity, lead time or inventory, these supply chains lack the extra resources needed to cope with unplanned events" (Melnyk 2007).

After goods are produced, they must still be distributed to the customer. The capacity of the distribution system varies greatly by mode and channel. If shipping internationally, the distribution system typically includes many more players, each of whom may be a potential bottleneck: surface, ocean and air carriers, brokers, freight forwarders, import/export agents, banks and customs offices (Ballou 2004). The ability to obtain necessary distribution services when needed is critical to all producers.

Raw material availability represents another aspect of resource limits. Although typically procured through a supplier, the raw materials for production may in some cases be obtained by the focal firm. For example, a mining company needs direct access to sufficient volumes of ore. In either case, the availability of raw materials is a major factor in the quantity and cost of goods produced.

One vulnerability factor that is often overlooked by firms in developed nations is the utility infrastructure, which in many cases is provided by governments or agents outside the firm. Without electrical power, water, sewer and communications

infrastructure, production will quickly cease, many times ruining product in-work. Many companies have identified the need for emergency power generation which automatically activates in the case of loss of outside supply. In addition, the quality of utilities may be important based on the sensitivity of the production process, for example, variation in the electrical voltage.

And finally, the most valuable asset of all production processes is human capital. Availability of a trained workforce is critical to continued operations, and during surge production additional labor is required through overtime and/or additional hires, i.e. contingent labor (Nollen and Axel 1996). A stable workforce limits the amount of training required, which can be a significant investment for a high-skilled job. Location is also important to the availability of workers as economic factors such as pay, housing and working conditions impact a firm's access to skilled workers. Without a skilled workforce it is impossible to run a truly effective organization (Norcross 2007).

Sensitivity

Sensitivity is the importance of carefully controlled conditions for product and process integrity. Sensitivity may cause a disruption in product flow or claims based on product liability. Product liability can result in large, unexpected losses attributed to a specific product. The loss may be due to defective design, production, storage, misuse or sabotage (Engineering and Safety Service 1995). Elements of sensitivity include utilization of restricted materials, product purity, fragility, complexity of process

operations, reliability of equipment, potential safety hazards, visibility of disruption to stakeholders, symbolic profile of brand and concentration of capacity.

First, if a product requires the use of restricted materials controlled either by government safety or environmental regulations, by import/export quota or by propriety restrictions, a supply chain is then very sensitive to input limitations (Lippman 2001). Also, sensitivity is created by demands for product purity that can be affected by the quality of inputs or the production process itself. Product purity is typically dictated not by the process but by the application of the product, and it is therefore important for managers to understand the downstream supply chain and consumer uses.

Additionally, increasing levels of outsourcing due to cost reduction programs and specialization requires accurately communicating design parameters and their sensitivities to the producers and suppliers (Riswadkar and Jewell 2007). However, the purity of raw materials is not only the level of product quality as the items leave the supplier's plant, but also that of the materials entering into your production process. Raw materials and finished goods may be fragile and susceptible to damage or degradation during storage and shipment. Therefore, it is just as critical to control and monitor the inbound logistics system as it is to control the distribution to customers, with the end result of delivering quality products.

Complex production operations also create a sensitive system. Increased risk of failures occurs as complexity and coupling increase, according to Normal Accident Theory (NAT) (Perrow 1984, 1994). In fact, some accidents occur "because the humans who operate and manage complex systems are themselves not sufficiently complex to

sense and anticipate the problems generated by those systems" (Weick 1987). Novak and Eppinger (2001) discuss sourcing options for products based on the level of complexity. However, even with significant planning, failures may occur in ways that had never before been identified due to the interaction of these complex processes (Rijpma 2003).

In contrast to the product or system view, equipment reliability must also be considered. Reliability is the probability that the equipment will satisfactorily perform its intended function under given circumstances, such as environmental conditions, operating time and maintenance for a specified period of time. Additional redundancy and increased design parameters (e.g. safety margins) can improve reliability, but many times at the expense of additional complexity (Rijpma 1997). Similar to equipment reliability, human accidents represent the failure of the human system. The associated reduction in worker productivity can contribute to a disruption and almost always creates additional expenses in terms of health care, recovery efforts, repair of equipment or replacement of damaged materials (Walton 1973).

Operations are also sensitive based on the visibility of disruption to important stakeholders: owners, shareholders, employees and the general public, based on the organization's design. Stakeholders may exert pressure on operations depending on their visibility to events. For example, a private firm may have a very involved owner, while a publicly held corporation may be more sensitive to media coverage of an event and the aftermath of investor confidence. Visibility of the stakeholders is a critical factor in the recent surge in corporate responsibility (Burke and Logsdon 1996).

The symbolic profile of a brand, considered an asset in advertising, can also create a vulnerability linked with deliberate threats and external pressures. The brand image may attract would-be attackers either based on the exploited gains obtained directly or through expanded media coverage simply because of the brand name. Brands such as Coca-Cola, Nike and McDonald's personify the United States and western capitalism. Brands represent positive traits such as quality, low-cost or functionality, but in contrast may also convey what they are against: competitors, political ideology, etc. (Ritson 2006).

And finally, the concentration of capacity creates a sensitivity threat to the supply chain from any other source of change. A regional draught, hurricane or flooding can be compounded if multiple sources of supply, production or distribution are concentrated in a single area. Even a minor impact to multiple assets can multiply if applied simultaneously in a complex and tightly coupled system.

Connectivity

Connectivity is the degree of interdependence and reliance on outside entities. The last century has seen a dramatic shift away from complete supply chain ownership to vertically integrated supply chains on global scales (Essletzbichler 2003). These additional nodes and links in supply chains create greater vulnerabilities to disruptions due to the scale of the network, number of import and export nodes, the reliance on specialty sources, the reliance on information flow and the degree of outsourcing. First, the scale of the supply chain network creates a system whose decisions are highly

interdependent (Siggelkow and Rivinsin 2005). It does not matter if a network of hundreds of suppliers and customers are local, regional, national or global – each firm boundary represents yet another vulnerability.

The unique complexities involved in international trade create time and cost burdens when supply chain networks cross import/export boundaries (Bowersox and Sterling 1982). Trade between countries of similar languages, cultures, economics and legal systems can be challenging; trade between developing countries brings additional issues and barriers. Many new opportunities for trade reside in the Third World. "In the absence of specialized intermediaries, regulatory systems and contract-enforcing mechanisms, corporations in emerging markets cannot access capital or talent as easily or as inexpensively as European and American corporations can" (Khanna and Palepu 2006). Emerging markets such as Argentina, Brazil, Chile, China, India, Indonesia, Mexico, Poland, South Africa and Turkey are current targets for global firms to access raw materials, labor and consumers, but carry significant burdens of vulnerabilities.

Another facet of connectivity is the reliance upon specialty sources. This situation can result from the use of a proprietary item, dependence on an item that has extreme economies of scale or incorporating a product that carries governmental restrictions on production or sale. Either way, a firm in this situation has limited options that lead to a greater risk of disruption.

In a similar way, information requirements create connectivity risks between supply chain partners. In today's age of electronic data interchange, firms within a supply chain are interconnected to very deep levels. Mapping the supply chain's data

flow will uncover tremendous amounts of data linkages, the effects of which can be immediate and devastating. For example, KLM Royal Dutch Airlines was forced to ground flights in Singapore and elsewhere because of a data disruption in code-share partner Northwest Airlines' reservation system when a contractor severed a US West Communications fiber optic line half-way around the world in Iowa (Sheffi 2005).

Finally, connectivity extends beyond suppliers and customers as firms move toward more outsourcing. In many cases this is limited to logistics functions such as inventory management, warehousing and distribution, but has recently moved into customer service operations, order processing and even manufacturing (Knemeyer and Murphy 2005; Mookherjee 2008). Many branded products are made by outsourced manufacturers and not the company whose label is on the outside. Cross (1995) views information technology (IT) as a critical support function that can be outsourced to a specialized supplier in order to "cut costs, gain more flexible and higher-quality IT resources and focus the IT department on activities that directly improve the overall business." These additional layers of management contribute to increased connectivity concerns.

Supplier and Customer Disruptions

Supplier and customer disruptions are the susceptibility of suppliers and customers to external forces or disruptions. Supplier disruptions are numerous and affect a firm's ability to produce goods and services, especially in an interconnected, global environment. Corporate profitability is directly affected when customers are disrupted in

terms of lower revenues due to decreased sales. In such an instance, additional burdens are typically also incurred, such as rising inventory costs or price mark-downs.

Supplier disruptions can be attributed to characteristics of the purchased product, the supplier's organization and market environment (Zsidisin 2003). Inbound disruptions can come from an infinite list of possibilities, such as supplier equipment failure, labor issues and weather conditions (Svensson 2000, 2002). Each issue, however, is directly related unto itself in terms of the supplier's own level of resilience. It is interesting to note that with current managerial thrusts to align supply chain performance metrics, research has repeatedly shown that cost and the resulting profitability are the only common measures that are relevant for negotiations between supply chain members (Peck 2005; Lambert 2006). Therefore, lean initiatives solely designed to reduce costs must be balanced with the brittleness to change that is created (Goldsby, Griffis and Roath 2007), hence lean can increase risks that directly threaten profitability. In addition, collaborative programs such as risk sharing and open data flow must consider the effects to overall system costs and profitability.

Customer disruptions are just as important to understanding vulnerability as supplier disruptions. Stemming again from the same infinite list of potential causes, customer orders may unexpectedly drop, in some case to zero. A firm must be prepared with flexible options to withstand short-term disruptions in demand and adapt as necessary if long-term impacts are expected. Strong collaboration programs boost relationships between supply chain partners and hope to provide a means of anticipating severe demand disruptions.

Capabilities

Capabilities are "attributes that enable an enterprise to anticipate and overcome disruptions" (Pettit, Fiksel and Croxton 2008). Earlier research defined 14 separate capability factors that can be managed to balance the inherant vulnerabilities in the supply chain. The goal for managers is to create a porfolio of capabilites that results in balanced resilience. The following sections develop each of the capability factors of the Supply Chain Resilience Framework.

Flexibility in Sourcing

Flexibility in sourcing is the ability to quickly change inputs or the mode of receiving inputs. This view of flexibility was segregated from other forms of flexibility due to the significant expanse of flexibility sub-factors, such as supply, operational, market, logistical, organizational and informational (Duclos, Vokurka and Lummus 2003). In the realm of supply-side flexibility, sub-factors include utilizing common product platforms, product modularity, multiple pathways, supply contract flexibility and alternate suppliers.

First, using inputs that are common to many finished products provides savings in inventory costs and lowers the risk of an individual stock out (Collier 1982; Baker 1985). Many automobile manufacturers reduce both design and assembly costs by creating common chassis for multiple vehicles. Fisher, Ramdas and Ulrich (1999) studied the effect of commonality in the automobile braking system, computing optimal inventory

levels based on cost and design factors. Saturn saved millions of dollars by redesigning their station wagon to use the same rear doors as the sedan.

In contrast to part commonality, product modularity provides a level of production postponement and reduction in work-in-progress inventory by designing multiple final uses for each component, creating a wider variety of end items. Modular items use pre-assembled components that are designed individually and quickly installed into the unique combination of finished good (Baldwin and Clark 1997). The assemble-to-order consumer electronics revolution was made possible through modularity of interchangeable components.

Next, by utilizing multiple pathways and skills, a firm can increase their flexibility by employing inputs more efficiently. Open flow structures in a manufacturing facility or cross-training on a naval vessel both allow for increased productivity during a multitude of situations. Similarly, supply contract flexibility can greatly reduce overall costs and increase customer service levels, without the need for an excess of alternate suppliers. Flexibility can be in terms of quantity to be purchased, accelerated or delayed delivery dates or even specific product mix. Eppen and Iyer (1997) provide an example in the flexibility provided by back-up agreements in the fashion industry where buyers withhold final orders until initial demand is realized. Contracting suppliers to reserve production capacity can become a win-win proposition in terms of limiting overstock markdowns and lost revenue.

A final aspect of flexibility in supply, developing over the past decade of globalization, is the use of alternate suppliers. Berger, Gerstenfeld and Zeng (2004)

studied the result of alternate suppliers on production by including both events that impact all suppliers as well as single-supplier disruptions. Having many alternate suppliers provides options in the event of either a single or multiple-supplier disruption. Sheffi (2005) summarizes procurement alignment as only being successful when combining deep relationships with a single (few) supplier(s) or shallow connections with many suppliers.

Flexibility in Order Fulfillment

Flexibility in order fulfillment is the ability to quickly change outputs or the mode of delivery outputs. Sub-factors include multi-sourcing, delayed commitment/production postponement, demand pooling, inventory management, alternate distribution channels and fast re-routing of requirements. First, the ability to quickly ramp up production to meet surge demand without carrying large amounts of excess capacity is extremely profitable when facing unpredictable or seasonable demand (Gerwin 1993). However, results of a study have shown that companies typically enhance shop-floor flexibility over down-stream flexibility, when the latter was shown to be more positively related to firm performance (Sanchez and Perez 2005).

One option that combines manufacturing and downstream flexibility is postponement (Alderson 1950; Bucklin 1965). "Postponement and speculation strategies offer opportunities to achieve delivery of products in a timely and cost-effective manner" (Pagh and Cooper 1998). Categories include form postponement (labeling, packaging, assembly and manufacturing) and time postponement (Zinn and Bowersox 1988). By

delaying final product differentiation and delivery, less expensive inventories can support a wider range of specialized end-items by pooling the risk of demand variability. Recent evidence continues to support product re-design to increase postponement options, thus improving customer service levels and lowering variable costs (Feitzinger and Lee 1995; Yang, Burns and Backhouse 2004, 2005; Davila and Wouters 2007).

Similarly, demand pooling improves flexibility and reduces inventory costs through statistical economies of scale that can be achieved in numerous ways, including inventory centralization, order splitting and emergency transshipments (Evers 1999). Effective inventory management is another critical tool for flexibility. Visibility systems provide knowledge of where assets are and inventory management combines this data with demand projections and current orders to best compute cycle and safety stock, as well as reallocating inventories as needed. This management system requires efficient data exchange among various internal functional departments and supply chain partners to create a more flexible, customer-driven process (Lau and Lee 2000).

Alternate distribution channels are important when a particular carrier has a disruption or if an entire network is disrupted, i.e. air cargo following the 9/11 attacks. Many firms use multiple carriers on a regular basis solely for this purpose. Others may simply have standing agreements or no-fee contracts that allow clauses to be quickly implemented in an emergency. For example, the US government augments Department of Defense airlift in emergencies with the Civil Reserve Air Fleet (CRAF), selected aircraft from U.S. airlines that are contractually committed when the need for airlift exceeds organic capability. To entice airlines to commit at least 30 percent of their fleet

to the program, the government guaranteed standard air cargo volume worth $379 million in 2007 and estimates more than $2.1 billion in additional business that is not guaranteed (Air Mobility Command 2007). Some firms, however, choose to look for cost reductions or service improvements through sole sourcing for transportation services. A case in point was Best Buy's partnership with UPS for truckload, LTL and recently small package shipments with their on-line stores (Cooke 2004). And finally, the ability to shift the assignment of an item to different production or storage sites can create the most profitable level of flexibility (Aprile, Garavelli and Giannoccaro 2006).

Capacity

Capacity refers to the availability of assets to enable sustained production levels, taking the form of reserve capacity, redundant capacity and backup capacity. This capability is measured as the maximum amount of manufacturing or service resources such as a facility, process, workstation or piece of equipment to accomplish its purpose over a specified time period (Collier and Evans 2006). Typically, firms purchase or create a specific level of output capacity based on expected demands with additional capacity to handle variations in demand as well as providing for production uncertainties such as equipment breakdowns and unscheduled change-over (Stock and Lambert 2001). This additional capacity can be labeled "reserve capacity," to include capability to meet limited surge requirements through sufficient levels of materials (such as raw materials and components), assets (such as tools, equipment and finished goods inventory) and labor. Physical goods stored as reserve capacity are considered safety stock, whether

held as input buffers, work-in-progress or finished goods (Graves, Willems and Zipkin 2000; Zinn, Mentzer and Croxton 2002; Croxton and Zinn 2005). Maintaining reserve production capacity is essential in service industries and in manufacturing may be much more cost-effective than holding reserves of high-value finished goods (Sheffi 2005).

In addition, multiple redundant resources can provide the same amount of capacity as a single or a few larger resources without consolidating risks of failures into a single facility or piece of equipment. This redundancy can entail employing a duplicate computer server at an off-site location to provide both processing capacity and redundant backup data in the event of power loss, cyber attack or physical damage at the primary location. This was successfully employed by the Cantor Fitzgerald brokerage, with main offices in the World Trade Center, with its primary trading system eSpeed replicating data and functionality of its New York and London offices (Vijayan 2001). Having a redundant resource can prevent a major disruption or prevent a minor event from causing a system-wide failure (Lerner 1986). However, redundant resources may require additional investment and maintenance costs plus added security concerns in regard to multiple, possibly inter-connected equipment (Sagan 2004). "[These] redundancies and all other safety measures should be designed in from the start and not added afterwards, since add-ons are disproportionately the source of accidents" (Perrow 1999).

Finally, backup capacity of the enablers of production, utilities such as electricity, water and communication, is a critical capability. Whether owned, leased or purchased, loss of these enablers can immediately affect operations if backup sources are not

available when primary sources are disrupted (Doucet 1991; Rose, Oladosu and Liao 2007).

Efficiency

Efficiency is the "capability to produce outputs with minimum resource requirements." The goal of efficiency is to reduce all cost drivers while still meeting customer demands. Sub-factors of efficiency are labor, production, asset utilization, waste elimination, production variability reduction and failure prevention. Consistently producing the most from labor and equipment will reduce overall costs for a given amount of output. One typical source of lost efficiency is process bottlenecks. Goldratt (1984) introduced the Theory of Constraints as a management philosophy in his seminal book, *The Goal*, which theorizes that at any given point in time, at least one constraint limits the system's performance thus potentially reducing system efficiency. The objective is to improve overall system efficiency without sub-optimizing a single stage at the system's expense.

Waste elimination is the heart of lean philosophy that was developed from the theories of Taiichi Ohno's Toyota Production System. Coined by MIT researcher John Krafcik, lean was publicized by Womack, Jones and Roos (1990) in *The Machine that Changed the World*. Research suggests that based on market and economic factors, there is an appropriate time and place for lean production, as well as other environments which fit a more agile or a combined *leagile* system (Towill and Christopher 2002; Goldsby, Griffis and Roath 2006).

Although within-specification products are not discarded or re-worked, they can still represent some amount of inefficient operation. Whether caused by equipment tolerances or human errors, reduction in product variability can contribute to overall system efficiencies. For example, consider a machine designed to fill product into 8 oz jars. In order to ensure that sufficient product is filled to meet labeling standards, the programming may be set to fill an average of 8.2 oz because of a historical filling error distribution. Tenets of 6-sigma can be used to find ways to reduce the variability and therefore set back the target fill weight; even with a minor reduction in the average fill per container the savings can be significant.

Failure prevention can potentially be the most profitable mode of ensuring efficiency, especially in high-volume production or process manufacturing where shut-down and start-up times can even exceed that of repairs. High Reliability Theory asserts that organizations can contribute significantly to the prevention of accidents (Rijpma 1997). These types of organizations have a culture of redundancy and methodically design for reliability. Preventative maintenance is a key investment that can significantly reduce system costs through planning of down-time to avoid even more costly repairs, rescheduling and recovery efforts.

Visibility

Visibility is the knowledge of the status of operating assets and the environment. The first point to note is that this knowledge is not simply data. Data must be readily available, timely, accurate and in a format that communicates necessary information.

Sub-factors of visibility include information technology, knowledge of asset status, information exchange and business intelligence gathering. In today's age of Electronic Data Interchange (EDI), Radio Frequency Identification (RFID) and web-presence, visibility can successfully come from many types of media, not only electronic – a phone call or memo can suffice in the right circumstance. However, with vast amounts of data being created in today's enterprises, electronic dissemination, filtering, monitoring and even pseudo-independent decision making can be extremely rapid and cost effective. We categorize the first sub-factor, information technology, as the visibility of internal operations and processes.

Second, for general efficiency and especially in times of crisis, the status of your assets including facilities, equipment, inventory and personnel is crucial to effective decision making. Converting this status data to knowledge requires dissemination to the right people, at the right time and in a form they can use. Third, visibility also extends beyond the firm among supply chain members. This knowledge contributes to supply chain confidence through sharing information such as current inventory position, procurement status, manufacturing schedules, distribution reliability, order status and demand forecasts (Christopher and Lee 2004).

And finally, business intelligence is both a process and a product that extends beyond the boundaries of even the supply chain (Jourdan, Rainer and Marshall 2008). The goal is to provide leading indicators of future trends and to predict the behavior of "competitors, suppliers, customers, technologies, acquisitions, markets, products and services, and the general business environment" with a degree of certainty (Vedder et al.

1999). In 2007, managers rated business intelligence as the 2nd most important application of information technology, just slightly behind security applications for antivirus protection (Luftmann and Kempaiah 2008). In all accounts, visibility is clearly an enabler of rapid, effective decision making to support normal operations and especially in turbulent times.

Adaptability

Adaptability is the ability to modify operations in response to challenges or opportunities. Adaptation provides firms with the capacity to cope with and adequately respond to change (Esper, Fugate and Davis-Sramek 2007). Sub-factors of adaptability are re-routing of requirements, strategic gaming and simulation, seizing advantage from disruptions, alternate technology development, lead time reduction and learning from experience. First, tenets of flexibility allow for adaptive measures in the form of a decision making process that can transfer production or distribution in the event of a potential or actual disruption at other point in the supply chain. Adaptability is knowing when and where to implement flexibility.

Next, although typically perceived as technology driven, gaming and simulations can greatly enhance an organizations ability to learn and adapt. Such events can take the form of senior leaders in a table-top role play of a hypothetical disruption or a pre-programmed war gaming scenario executed on actual systems. Although primarily a training aid, simulators of aircraft flight provide pilots a realistic environment of sight, sound and motion, recreating events that rarely occur in real-life and would be too risky

to induce. These systems allow pilots to learn from events that have never actually experienced but also allow designers to adapt hardware, software and interfaces to improve safety and efficiency. Another type of simulation is a data model. The simulation model addresses the impact of interrelated alternatives and activities in an information-rich environment (Pruett 1990). Simulation allows the choice of different system settings to improve the performance of the entire systems; therefore the investments and potential rewards of initiatives can be predicted with some level of confidence (Hong and Nelson 2006).

Seizing advantage from disruptions is another form of adaptability that can be very profitable for a firm. In service industries, studies have shown that beginning the service strong and ending in delight is more important than any problems that arose during the majority of the encounter (Johnston 1995). Additionally, good recovery can create even more customer goodwill than if nothing had ever gone wrong in the first place (Hart, Heskett and Sasser 1990). If, however, the disruption is with a competitor's supply chain, recognizing the opportunity and acting swiftly can dramatically increase revenues. If customers are please with your substituted products and services, a permanent shift can occur and market share expanded.

Technology can also be a great source of adaptation. Integrating new technology with adaptable processes can greatly increase throughput and reduce lead time. In the area of product development, reducing the research, design, prototyping and manufacturing processes can allow a firm to be first-to-market. Other advantages such as cost reductions and quality improvements can be significant benefits of technology

innovation. Similarly, lead time reduction is an adaptive force. Lead time, or total order cycle time, is caused by production, order processing, transportation and all other stages that require time to fulfill customer orders. Lead time expands the forecasting horizon thus increases the level of uncertainty. Additional uncertainty affects customer service levels through time variation in processes: late deliveries, order processing backlogs, production equipment failures, etc. Even with zero uncertainty in lead-time, a firm may accurately predict reorder arrivals to minimize inventory; however, long transit times increase pipeline stock and long production batches increase work-in-progress – all contributing to high supply chain expenses. "Efficiency and effectiveness of channel systems may be improved by giving explicit recognition to demand and lead-time variability" (Speh and Wagenheim 1978).

The final category of adaptability is learning. In order to stay competitive, firms must be learning organizations (Hanssen-Bauer and Snow 1996). Analyzing disruptions following recovery actions and implementing changes leads to improvement; this feedback stage must, however, be formalized within the organization (Perrow 1999). Many companies simply solve a disruption then move on to the next "fire." Others may discuss lessons learned, even informally implementing ideas only to find that the organization quickly reverts back to the old status quo. Unfortunately for risk-adverse managers, the price of this adaptability may be unstable processes with unpredictable outcomes (Eisenhardt and Martin 2000), but firms that risk changing their products, processes and organization will command a competitive advantage over the long-term.

Anticipation

Anticipation is the ability to discern potential future events or situations. The goal of anticipation is to prevent potential disruptions if possible, and to mitigate the effects of a disruption if not avoided. Capability sub-factors of anticipations are demand forecasting, risk identification and prioritization, monitoring and communicating deviations and "near misses", recognition of early warning signals, contingency planning and preparedness, and recognition of opportunities. Frequently there is a time lag between awareness of an impending event and the occurrence of that event (Makridakis, Wheelwright and Hyndman 1998). The ability to correctly forecast demand within sufficient lead time feeds the procurement, production and distribution processes to operate most efficiently and improve customer service levels. Forecasting methods can be quantitative or qualitative, but some events will still be unpredictable (e.g. a technology innovation).

Risk identification, as with forecasting tools, requires at least some historical data or subjective estimates, as discussed in Chapter 2. Where data is available, historically accurate and the assumption that the past is representative of the future holds relatively true, managers can use traditional risk management techniques to prioritize risks to make valuable investments in mitigation programs (Carter 1972). However as previously discussed, these assumptions do not always hold, but when valid, risk management is a critical component of a resilience development process. In addition, the complexities in the modern environment create vast interdependencies that may invalidate even the simplest of risk assessments (Kunreuther 2006).

Near-miss programs are in fact anticipation capabilities that improve corporate environmental, health and safety (EHS) performance through the identification and management of events that approach the limits of, but do not exceed, normal operating parameters. Many major accidents have had previous near-misses: 1986 Space Shuttle Challenger explosion, 1997 Hindustan refinery explosion, 1998 Morton reactor explosion and 1999 Paddington train crash (Phimister et al. 2003). Bird and Germain (1996) report that for each serious injury accident there are 10 events with minor injuries, 60 events with property damage and 600 other incidents without any loss at all; therefore, learning from these prior events can potentially prevent future accidents.

For supply chain disruptions where events build over time, the recognition of early warning signals can provide a key capability. Many firms are now employing event management systems that automatically monitor key indicators on a real-time basis to identify the early warnings signals of an impending disruption. The systems "gather data on suborders in interorganizational settings, focus on proactive monitoring activities with classified critical order profiles and analyze, interpret and distribute information" (Bodendorf and Zimmermann 2004). Watkins and Baserman (2003) warn leaders that "the signs of an impending crisis often lie all around us, yet we still don't see them." Identifying and taking early action can make the difference between a disruption or a smooth return to normal operations.

A myriad of programs encompass the stage of anticipation where firms prepare for the worst: disaster preparedness, contingency planning and business continuity planning. Each attempts to identify major events that could disrupt operations and to

institutionalize a set of pre-arranged reactions in order to quickly return to normal operations with minimal impact. In studying how and why firms create a business continuity plan, Zsidisin, Melnyk and Ragatz (2005) identified a 4-stage process of creating awareness, prevention, remediation and knowledge management, embedded with continual feedback. “For years, companies’ use of scenario-and-contingency planning tools lagged behind the average for management-tool use overall; that changed abruptly after 9/11” (Rigby and Bilodeau 2007). In 2006, Rigby and Bilodeau’s survey reported 72 percent of firms utilizing contingency planning, up from a worldwide average of only 38 percent 1992. However, as risk identification of all possible disruption scenarios is infinite (Sheffi 2005), firms can not prepare for every eventuality, but advance planning and training for the most common or most devastating potential events can significantly improve a firm’s chances for survival.

And finally, in contrast to the previous discussion of the negative impacts of supply chain disruptions, an enterprise has the capability to recognize opportunities, both emanating from within the firm and from without. When new product innovations are created, how quickly does the firm recognize the potential and use its other capabilities to expeditiously get it to market? Or, when a competitor faces a disruption, how quickly and in what quantities can your firm substitute your products to meet the customers’ needs? Anticipating your next opportunity is the first step to making it happen.

Recovery

Recovery is the ability to return to normal operational state rapidly. Unfortunately, many view recovery as the sole essence of resilience, while others see

recovery as the sole goal, regardless of the cost. However, recovery is only necessary when change is not well anticipated and normal systems, potentially less expensive and more proactive, fail. Empirical data from Chapter 2 categorized recovery into the ability to quickly mobilize resources, communicate the recovery strategy, manage the crises and mitigate the consequences of the disruption.

First, quickly mobilizing resources is critical to beginning recovery efforts. Quick reaction can limit the overall severity of a disruption in terms of profitability or loss of life. For natural disasters, the Federal Emergency Management Agency (FEMA) has taken a lead role in providing assistance to government agencies, corporations and individuals to prepare for more effective recovery. For example, the National Response Framework is "built upon scalable, flexible and adaptable coordinating structures to align key roles and responsibilities across the nation, linking all levels of government, nongovernmental organizations and the private sector" (FEMA 2008). Identifying the event and then mobilizing the right resources, as soon as possible, is the goal at this stage.

Communicating the recovery strategy throughout an event is the second step. The impact of a disruption may be less severe if the supply chain is embedded with the capability to quickly detect and disseminate pertinent information pertaining to the disruptive event (Craighead et al. 2007). The next aspect of recovery is crisis management. Managing the crises is more than the direct reactions to an event, but includes managing customer and supplier relationships as well as public impressions on the event and on the brand's reputation. An example of successful crisis management comes from the 1982 cyanide-lacing of Tylenol capsules. Johnson & Johnson's decisive

actions, combined with effective crisis management with shareholders and the public, resulted in a regaining of market share by the second quarter of the following year (Lewin 1982, 1986; Sheffi 2005).

And finally, consequence mitigation is the effectiveness of the recovery actions directly. The severity of a disruption will decrease "with the capability to proactively and/or reactively respond quickly and effectively to correct the disruptive event" (Craighead et al. 2007). The goal is to return to normal operations as quickly as possible, with the least impact to profitability. "A good recovery can turn angry, frustrated customers into loyal ones" (Hart, Heskett and Sasser 1990).

Dispersion

Dispersion is the broad distribution or decentralization of assets. Dispersion of assets is more than just physically separating the location of production facilities. Dispersion includes not only facilities and equipment but also the human workforce, leadership and downstream customers themselves (Cranfield 2003; Hamel and Valikangas 2003; Rice and Caniato 2003; Sheffi 2005). These assets are required for normal operations as well as emergency responses dictated by disaster management plans (Namel and Ward 1983; Hale and Moberg 2005). Leadership includes the personnel with the necessary skills, knowledge and authority to make critical decisions for the firm. The formal transition of power can be formally dictated as in the military's chain of command or informally guided in the firm's culture of empowerment (Halperin 1972).

Market dispersion is essential to business continuity in terms of sales if consumers (or downstream business-to-business customers) are unable or unwilling to purchase your product or service. Market dispersion protects against a localized weather threat (hurricane, draught, etc) that may prevent individual travel to stores or disrupt the connecting distribution networks, such as during Hurricane Katrina in 2005. In many instances, demand shifts in one geographical area will be offset by opposite shifts in another region.

Collaboration

Collaboration is the ability to work effectively with other entities for mutual benefit. Collaboration can improve the firm's top line as well as the bottom line (MacCormack and Forbath 2008). Sub-factors include collaborative forecasting, transparency of information, postponement of orders, product life cycle management and risk sharing. First, although just about all firms forecast demand and many share their forecasts with suppliers and/or customers, few actually collaborate to create a joint forecast. Terwiesch et al. (2005) found that when individual forecasts are shared and demand is not realized as planned, suppliers penalize buyers for unreliable forecasts by providing lower service levels, while buyers penalize suppliers that have a history of poor service by providing them with overly inflated forecasts. Neither situation benefits the supply chain.

Transparency can take many forms and is typically defined as "the two-way exchange of information and knowledge between customer and supplier" (Lamming et al.

2001). However in a collaborative environment, this flow of information is for joint purposes. In addition, as trust builds between supply chain members, free access to read and write shared data is a sign of improved collaboration, increasing efficiency as data is entered only once and by the person with the most accurate information. In doing do, transparency has been shown to positively influence customer satisfaction (Zhang, Vonderembse and Lim 2006). On February 1, 1997, a fire at one of Aisin Seiki's plants threatened to halt Toyota-group operations for weeks; however, quick reaction and transparent information sharing on product design, specifications and techniques between Toyota's engineers and their network suppliers were the keys to a quick recovery (Nishiguchi and Beaudet 1998).

The next area of collaboration is postponement of orders. Postponement is typically viewed from the manufacturer's point-of-view in delaying the finalization of production or location (Zinn and Bowersox 1988; Pagh and Cooper 1998; Van Hoek 2001); however, in this collaborative sense we refer to the offering of a customer to delay their order for the overall benefit of the supply chain when a producer faces a disruption. For example, rather than allocating scarce resources to customers based on fair-share of orders or based on previously contracted delivery dates, negotiations can help compute the true "need date" of each customer and their cost of potential delays. If sufficient trust is built between partners, customers may willingly delay orders thus freeing up stock for other customers or allowing for a more cost-effective recovery plan to be implemented.

Involvement of suppliers and customers in a joint product life cycle management program can not only increase profitability but prolong the revenue stream. Through the

phases of rapid growth, transition, maturity and end-of-life, collaborative planning is fundamental. For products with service ties, revenues follow the installed product base through the life cycle; however, profits typically lag behind product sales. In fact, in a study on the electronics industry, “some 70 percent of service income came as computer shipments were on the wane” (Potts 1988). Studies report a “clear relationship between the intensity of the collaboration and the positive effects experienced from the collaboration” (Sandberg 2007).

Collaborating with suppliers and customers in the form of risk sharing can benefit the supply chain. Viewed singularly, firms make investments and bear risks due to uncertain outcomes but do so in expectation of rewards beyond their cost of capital. In supply chain collaboration, risk sharing typically takes the form of shared investments based on the relative size, asset specificity and strategic importance of the investment (Ojala and Hallikas 2006). Ojala and Hallikas (2006) performed case studies with two global industrial manufacturers and nine of their suppliers, four in the metal sector network and five in electronics. They found that closer cooperation created pressure for increased investment. In situations of power imbalances in the supply chain, typically the firm with greater financial strength bears a larger burden of investment risk, while negotiating a greater potential for rewards commensurate to their investment share. For example, many large manufacturers may desire their suppliers to modernize equipment in order to improve product quality or supplier capacity. A small supplier may not be willing to bear the risk of a major investment for fear that the manufacturer may change suppliers or eliminate the product line. In such a situation, a joint investment decision

would have profit sharing agreements integral to the decision, typically with future profits divided in direct relation to the percentage of investment committed. This rule for profit sharing is termed ‘equity rules’; however, business practices typically take the form of 50/50 sharing over the ‘equality rule’ in order to reduce conflict between supply chain partners, especially with investments or returns are difficult to quantify exactly (Jap 2001). This situation does not change as the stakes increase (Hoffman, McCabe and Smith 1996) or with differing nationalities (Roth et al. 1991). Jap (2001) concludes that “the careful application of equity- and equality-sharing principles applied judiciously to specific types of complex collaborations can improve the participants’ satisfaction with the collaboration, their perceptions of fairness of the outcomes and their willingness to collaborate again in the future.”

Although cooperation and long-term collaboration resulting from equality and equity sharing are important, incentives schemes used to entice desired behavior vary significantly in practice. Lambert (2006) gives two examples of partnerships in which agreements allow the supplier to retain 100 percent of the initial benefits. In the case of Masterfoods USA, their suppliers keep the savings until all expenses are recouped and an agreed upon level of profit is reached, then all of the future savings are kept by Masterfoods USA. In a similar example presented by Lambert, Wendy’s International includes a standard format in their Product Service Agreements that specifies that the supplier will benefit from all of the first year’s savings, split them equally during the second year and all future savings retained solely by Wendy’s. However, when the process improvement requires no investment by the supplier (i.e. no risk sharing),

Wendy's retains all of the savings. Hartley, Greer and Park (2002) studied Chrysler Motor Company's Supplier Cost Reduction Effort (SCORE) to induce process improvements while sharing risks. In this instance, Chrysler negotiated with suppliers to keep 50 percent of any savings attained that exceeded their annual SCORE cost-reduction goals. Here the channel leader shares with its supplier—on an equality basis—the greater than expected savings, an enticement to the supplier to make the joint investment profitable for both parties. A final example of successful risk sharing comes from Blockbuster video. Through contract modifications with the suppliers of rental movies, Blockbuster was able to greatly increase their customer service levels with a new risk sharing initiative designed to increase on-the-shelf offerings because of lower per-item cost, combined with sharing of the revenue to the movie houses (Sheffi 2005).

Organization

Organization as a capability is the human resource structures, policies, skills and culture of a firm. Organizational sub-factors include creative problem solving, accountability and empowerment, diversity of skills, substitute leadership, learning and caring.

Creativity is considered to be the source of new and competitive ideas through which an organization positions itself in its environment (Van Woerkurn, Aarts and de Grip 2007). Leadership can encourage or stifle creativity within their firm. The good news according to Baker (2004) is that "Every person and every organization possesses creative capacity." The problem lies in balancing the freedom needed to spur creativity

with the business realties of profitability. Organizations must balance the freedom of empowerment with accountability, the obligation to answer for an individual's actions. However, "the most common mistake made by organizations looking to empower frontline employees is to take too lightly what they are asking the managers in the middle to do" (Forrester 2000). They may feel their authority is being usurped while still bearing the responsibility for performance. Senior management must frame and communicate the vision of the firm to personnel at all levels, as well as clearly setting limitations of individual actions, policies for tracing resources and the consequences for failure and success. An interesting point to note in regards to accountability within internal regulatory organizations: organizations need strict accountability but there are limits to unchecked empowerment. In study of the Challenger tragedy, analysis revealed that "regulatory effectiveness was inhibited by the autonomy and interdependence of NASA and its regulators" (Vaughan 1996).

Another organizational capability is diversity of skills and experience. This "cross-training" is designed to create workforce flexibility. "Cross-training workers across different departments offers the flexibility to deploy workers to changing workloads and thereby produces better…performance" (Yang 2007). A similar concept is creating a workforce trained and equipped to transition leadership in the event of disruptions. Whether due to communications break-downs, health issues or leadership overload, an organization that can smoothly implement a transition in leadership will avoid panic or paralysis that typically results in emergencies.

A learning organization institutionalizes several tactics to improve: best practices, benchmarking, customer/supplier feedback and post-mortems, to name a few. Several lessons have been learned, however, to the success of learning: no tool is one-size-fits-all, people are more important than the tools, enable the organization to use the tools and develop programs to make the changes last (Yarrow, Hanson and Robson 2004). As suggested several times, the critical asset of a firm is its employees with their knowledge, experience and creativity. An organization that has a true culture of caring for its employees will foster both security and loyalty. Security meets a person's lower-needs while loyalty limits turn-over of these valuable resources.

Market Position

Market position is the status of a company or its products in specific markets. This category of capability contains sub-factors of brand equity, customer loyalty, market share, product differentiation, customer relationships and customer communications.

Brand equity is the value a customer places on a branded product or service. A brand-name alone without any tangible assets can be of significant value. Brand equity ensures a high probability of purchase intention, and thus a high probability that the consumer will prefer the same product again (Pugh et al. 2002). In terms of disruptions, brand equity is identified as a prevailing advantage that spans the entire failure and recovery sequence (Brady et al. 2008).

Customer loyalty not only is a measure of repurchase intensions, but also provides a measure of protection from lost sales during a disruption and helps regain sales

afterwards. Most surveys across industries show that keeping one existing customer is five to seven times more profitable than attracting one new customer (Roberts-Phelps 2001). Therefore, customer loyalty is a better predictor of profitability than even market share (Pugh et al. 2002).

Market share is the percentage of a category or segment's retail sales obtained by a brand or company. Market share is won one customer at a time (Hart, Heskett and Sasser 1990). However, the accumulation of a large customer base relative to competitors provides a measure of power in the market place, such as the ability to institute new product changes or pricing structures. Competition will typically follow the market leader, quickly reducing short-term gains of new introductions. In the event of a general disruption affecting all suppliers, the greatest burden for recovery is placed on the firm with highest market share; however, this also provides for fewer competitors as substitutes.

Competition between similar high quality products drives prices down, thus eroding profitability (Shaked and Sutton 1982). In the event of a disruption resulting in a retail stock-out, options available to consumers include: 1) substitute the item they sought, 2) delay the purchase and 3) leave the store and either forgo the purchase or search for the item elsewhere (Zinn and Liu 2001). Significant product differentiation will limit the consumers' ability to substitute competitors' offerings, encourage delay of purchase and provide incentive for a search elsewhere. With either choice, strong product differentiation will protect long-term revenues. At the business-to-business tiers,

product differentiation may be an even more important capability as orders are typical very large and sold to a smaller, professional customer base.

Another form of differentiation is in relationships in the supplier-customer dyads. In order to coordinate complex operations, all corporate functions must be actively involved in developing inter-firm relationships in order to align corporate resources with the profit potential of each relationship (Lambert 2006). Formally developing and documenting relationships at the appropriate level of partnership is crucial to any successful business relationship (Lambert, Emmelhainz and Gardner 1996). Once established, developing an appropriate level of trust is necessary to understanding the changing needs of your customers, especially in the event of a time-critical disruption.

Finally, the details and frequency of communications between supply chain members contributes to overcoming disruptions. Providing customers with accurate data on projected and current events builds trust. Receiving timely and accurate feedback from customers will improve a firm's ability to anticipate and adapt to current problems and future change. Knowing how to best meet their needs is essential for building and maintaining market share.

Security

Security is the level of defense against deliberate intrusion or attack. Security's primary objective is prevention, either through deterrence, early identification or restrictions. "Security investments by their nature do not directly increase revenues but are intended to prevent costs—when effective, supply chain security measures prevent

disruptions, supply chain security breaches, product adulteration and brand/franchise destruction" (Rice and Spayd 2005). Lee and Whang (2005) evaluated employing Total Quality Management concepts with new technology and re-engineered operational processes to achieve higher supply chain security at lower cost. Lee and Wolfe (2003) call for multiple measures to ensure supply chain security: detection, network visibility, flexible sourcing, balanced inventories, design for security and demand-based management. Security sub-factors include layered defenses, access restrictions, employee involvement, collaboration with governments, cyber-security and personnel security.

"Compromised security at any link along the supply chain can prejudice the entire chain. Hence, attempts to secure the supply chain have relied on the concept of layered security" (Sarathy 2006). Layered defenses are effective at both deterring and restricting access. A deliberate threat may easily breach one layer of security, but multiple layers will require additional effort and time to defeat.

In the area of physical security, employing access restrictions is critical to safeguarding personnel, property and ideas. Restrictions can be created through measures such as identification badges and locks, facility designs such as gates and fences or other measures like guards and cameras. More advanced responses to limit access are extensive background checks and vulnerability tests by outside experts (Rice and Caniato 2003). Employee involvement in security is another necessity in any security program. Each employee should be constantly aware of their surroundings and required to report any unusual activities.

Firms must also collaborate with governments to ensure security, whether local facility theft deterrents, in-transit security or import/export measures. In fact, the first of Russell and Saldanha's (2003) five tenets of security-aware logistics and supply chain operations is that companies need to "partner with local, state and federal government organizations that impact the movement of freight." Currently, the model is the Customs-Trade Partnership Against Terrorism (C-TPAT) program:

> C-TPAT is a voluntary government-business initiative to build cooperative relationships that strengthen and improve overall international supply chain and U.S. border security. C-TPAT recognizes that U.S. Customs and Border Protection (CBP) can provide the highest level of cargo security only through close cooperation with the ultimate owners of the international supply chain such as importers, carriers, consolidators, licensed customs brokers and manufacturers. Through this initiative, CBP is asking businesses to ensure the integrity of their security practices and communicate and verify the security guidelines of their business partners within the supply chain. (US Customs and Border Protection 2004)

In the future, the importance of voluntary programs is likely to increase (Rice and Spayd 2005). As global trade continues to grow, integrating with all types of government security throughout the entire transportation system, as well as at facilities worldwide will be imperatives for safe, efficient operations.

The next sub-factor is cyber-security, defined as the protection of information against unauthorized disclosure, transfer, modification or destruction, whether accidental or intentional. With the increasing amounts of digital information stored within a company's computer system, transferred between supply chain members and in many cases directly with consumers, securing this information from theft and tampering is vital. Rice and Caniato (2003) address information security in terms of hardware (firewalls, dedicated networks, audits of partners' systems, etc.) and software (intrusion detection,

anti-viruses, passwords, education, training, etc.). DaVeiga and Eloff (2007) propose an Information Security Governance framework encompassing leadership and governance, security management, security policies, security program management, user security management, technology protection and operation security. Recent media attention to the theft of customer identification data and credit card account numbers raise the bar in the scale of potential losses and liabilities (Associated Press 2008).

The final sub-factor of security is the protection of a firm's most valuable assets: its personnel. Going far beyond traditional workplace safety measures, protecting your employees is now a requirement on- and off-duty. For example, prevention measures against the Avian Flu include recommendations for poultry workers, laboratory technicians, food handlers and overseas travelers (OSHA 2006). For overseas travel, travel briefings and security measures are critical. Many firms hire overseas security companies to report on local conditions to best inform travelers prior to departure. These firms may also provide tracking, escort, notification and emergency evacuation services while employees are in-country (Pomeroy 2004). Most employers are required either to obtain coverage under the Defense Base Act (DBA) or a waiver, but this simply does not provide the scope or magnitude of insurance coverage needed (Mueller 2004). Keeping your workforce vital and efficient is even more important today.

Financial Strength

Financial strength is the capacity to absorb fluctuations in cash flow. Sub-factors represent financial reserves and liquidity, portfolio diversification, insurance coverage and price margin.

Financial reserves are critical to sustaining operations during periods of disruption, either due to reduced revenue from customer disruptions, reduced receivables from suppliers unable to make timely payments or from extra expenses incurred during recovery operations (Hamel and Valikangas 2003). Portfolio diversification means more than financial spread of cash reserves – multiple product lines in a myriad of businesses can reduce the relative magnitude of a point disruption. Diversification can occur without globalization; however, many firms choose to expand their influence through multiple international markets with common and/or unique offerings, although short-term loses may result (Freund, Trahan and Vasudevan 2007).

Businesses use many forms of insurance to protect against major loss. Insurance provides coverage through a contract that binds the insurer to indemnify another against specified loss in return for premiums paid. Businesses may protect the value of physical property (facilities, equipment and inventory), intellectual property rights (patents, trademarks and copyrights) and employees (worker's compensation, health and life insurance). Firms also insure their organizations against liability from injury or negligence. For non-profit firms, Directors' and Officers' liability insurance (D&O) protects leaders from personal liability and financial loss arising out of wrongful acts committed or allegedly committed in their official duties. Types and levels of insurance

are a risk management decision; however, government regulations provide mandatory guidelines for worker's compensation under the Federal Employment Compensation Act and state labor codes. Recently offered Trade Disruption Insurance (TDI) protects against disruption in the supply chain, even when there is no physical loss or damage to the policyholder's assets (Miller Insurance 2008). Disruption may be caused by political events including embargos or terrorism, or physical events such as closure of a navigable waterway or natural perils. An example of an appropriate application of Trade Disruption Insurance includes a fuel supply company making annual deliveries to remote regions of Alaska (Miller Insurance 2008). If road conditions during the limited delivery window each year do not allow trucks to traverse the desolate terrain, then TDI can cover the extra costs associated with delivering the essential fuel via air. Being able to continue the revenue stream can be a competitive advantage, as well as improve cusomter loyalty by the assurance that deliveries will not be delayed or halted.

Expected utility theory has often been invoked to explain the purchase of insurance, but it fails to adequately predict responses to very low probability situations (Ganderton et al. 2000). When low probability events produce large losses, previous managerial decisions often seem confused or perverse in hindsight. Camerer and Kunreuther (1989) reveal a dichotomy in perceptions, where some individuals downplay or dismiss low probabilities (optimism and threshold biases) and others overestimate or exaggerate low probabilities (conjunction and availability biases). Ganderton et al. (2000) finds evidence of effects that still remain to be explained, such as the negative effects of repeated exposure to events. However determined, each firm in the supply

chain must determine the appropriate types and levels of insurance which can be used to mitigate the effects of disruptions.

The final element of financial strength lies in a product's price margin. Research identified a larger set of recovery options available to product managers whose products carried a higher price margin (Pettit, Fiksel and Croxton 2008). From expedited shipping to buying product from competitors as "pass through," the cost of a lost sale for a high-margin product justifies most any expenditure, especially if considering the life-time profit potential of the effected customers. However, in corollary to this benefit, many high-margin products have short life-cycles where massive discounts negate potentially high margins when sales are not made soon after production.

Complete listings of factor variables and definitions are in Table 3.3 and 3.4.

Research Question

- How can supply chain resilience be measured?

Research Objectives

- Develop a measurement tool that can be applied to a generic supply chain.
- Validate the assessment tool.
- Provide a method of analysis and presentation of results.

Variable	Vulnerability Factor	Definition
V1	Turbulence	Environment characterized by frequent changes in external factors beyond your control
V2	Deliberate threats	Intentional attacks aimed at disrupting operations or causing human or financial harm
V3	External pressures	Influences, not specifically targeting the firm, that create business constraints or barriers
V4	Resource limits	Constraints on output based on availability of the factors of production
V5	Sensitivity	Importance of carefully controlled conditions for product and process integrity
V6	Connectivity	Degree of interdependence and reliance on outside entities
V7	Supplier/Customer disruptions	Susceptibility of suppliers and customers to external forces or disruptions

Table 3.3: Vulnerability Factors ***(re: Table 2.3)***

Variable	Capability Factor	Definition
C1	Flexibility in Sourcing	Ability to quickly change inputs or the mode of receiving inputs
C2	Flexibility in Order Fulfillment	Ability to quickly change outputs or the mode of delivery outputs
C3	Capacity	Availability of assets to enable sustained production levels
C4	Efficiency	Capability to produce outputs with minimum resource requirements
C5	Visibility	Knowledge of the status of operating assets and the environment
C6	Adaptability	Ability to modify operations in response to challenges or opportunities
C7	Anticipation	Ability to discern potential future events or situations
C8	Recovery	Ability to return to normal operational state rapidly
C9	Dispersion	Broad distribution or decentralization of assets
C10	Collaboration	Ability to work effectively with other entities for mutual benefit
C11	Organization	Human resource structures, policies, skills and culture
C12	Market position	Status of a company or its products in specific markets
C13	Security	Defense against deliberate intrusion or attack
C14	Financial strength	Capacity to absorb fluctuations in cash flow

Table 3.4: Capability Factors ***(re: Table 2.5)***

METHODOLOGY

In accordance with Grounded Theory development (Glaser and Strauss 1967), the categories developed in the Supply Chain Resilience Framework (Pettit, Fiksel and Croxton 2008) were derived through empirical evidence and additional evidence is necessary to validate these concepts. Therefore, a two-step process was selected to measure then validate. First, an assessment tool was created to measure each element of the Supply Chain Resilience Framework. Seven firms desiring to investigate their supply chain resilience volunteered to participate in the initial fielding of the assessment tool. Each firm selected one of their supply chains of current interest for assessment, focusing on a particular product, product-line or product-family representing similar characteristics, network structure and market volatility. Second, to determine the validity of the assessment tool, a series of focus groups were conducted with each participating firm using a multiple case study methodology in order to evaluate several recent disruptions to qualitatively validate the assessment tool. The goal of focus groups is not to promote consensus-building or decision making, but is to gather a broad base of information on complex issues (Morgan 1996). In this way, a complete evaluation of the assessment tool and its ability to accurately measure the construct of resilience was accomplished.

Although a single case study can describe the existence of a phenomenon (Siggelkow 2007), multiple-case studies typically provide a stronger base for theory building (Yin 2003). Therefore, this research combines seven assessments from a wide variety of heterogeneous supply chains followed by multiple disruption case studies at

each firm in order to fully justify the theory building from Chapter 2 (Eisenhardt and Graebner 2007). The use of multiple cases also "enables comparisons that clarify whether an emergent finding is simply idiosyncratic to a single case or consistently replicated by several cases" (Eisenhardt 1989).

Assessment Tool, SCRAM^{TM}

Instrument Development

Based on the Supply Chain Resilience Framework (Pettit, Fiksel and Croxton 2008), a survey-based assessment tool – the Supply Chain Resilience Assessment and Management (SCRAM^{TM}) – was created to subjectively measure each factor and sub-factor. Due to the vast scope of supply chain resilience, employing multiple items per sub-factor was not practical in order to maintain a reasonable survey length (Dillman 2000). In order to determine internal priorities and compare results between heterogeneous companies, the survey concluded with questions rating the relative importance of the factors (Lambert 2006). Of concern during survey development was the large number of questions to represent the resilience factors and sub-factors (21 and 111, respectively). Survey responses are in ordinal form from the Likert Scale "Disagree/Agree," ranging from 1 to 5. Main factor scores are computed from the average of 3 to 9 sub-factors. As no assumptions are made to the distribution of the data, only factor means are used in rank order per the instrument's ordinal scale. Considerable care was made to word each question and response in a parallel manner to assist

participants in responding both quickly and accurately. A complete listing of the final assessment tool is listed in Appendix I.

Instrument Refinement

Following a pre-test by academics and practitioners, a larger-scale pilot test was implemented at Limited Brands utilizing the participants of the initial focus groups in a continued effort to refine the tool prior to implementation (N = 15, response rate of 75 percent). As multiple measures were categorized to represent resilience factors, the refinement process checked for unidimensionality of factor measures that include multiple variables. Cronbach's alpha was used as an unbiased estimator of internal consistency of responses based on the average inter-item correlation (Malhotra 1993). Well-developed scales will have a Cronbach's alpha of 0.7 or greater; however, others propose lesser values as acceptable in exploratory research (Hair et al. 1998; Loehlin 1998; Min and Mentzer 2004). Using a lower limit of Cronbach's alpha of 0.5 for this exploratory study, four of the 21 factors fell below this threshold for the pilot study, see Table 3.5. However, given this small sample, the decision was made to prioritize retaining individual sub-factors that could provide managerial insight over the removal of items simply to refine the unidimensionality of the scales, as analysis was conducted at both the factor and sub-factor levels. Therefore, following slight revisions to survey questions (e.g. adding "very" and "significant" to ensure questions were worded in a more parallel structure to support the Agree/Disagree Likert scale), it was determined that

the informational value of all sub-factors outweighed any minor improvement in factor measurement, especially due to the exploratory nature of this study.

	V1	V2	V3	V4	V5	V6	V7
Number of Items	6	6	6	6	9	5	2
Cronbach's Alpha (Pilot sample)	0.819	0.874	0.845	0.806	0.829	0.536	0.918
Sample size*	13	13	14	14	10	15	14
Cronbach's Alpha (Main sample)	0.651	0.756	0.746	0.730	0.704	0.745	0.756
Sample size*	138	134	142	105	102	130	142
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
Number of Items	5	6**	3	5	4	6	6
Cronbach's Alpha (Pilot sample)	0.617	0.613	0.584	0.463	0.141	0.695	0.921
Sample size*	8	13	13	11	12	10	12
Cronbach's Alpha (Main sample)	0.288	0.677	0.515	0.701	0.813	0.708	0.803
Sample size*	75	90	96	108	123	91	99
	C8	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
Number of Items	4	5	5	6	6	6	4
Cronbach's Alpha (Pilot sample)	0.572	0.438	0.394	0.565	0.920	0.796	0.572
Sample size*	15	15	10	15	14	7	15
Cronbach's Alpha (Main sample)	0.682	0.461	0.615	0.779	0.763	0.896	0.682
Sample size*	136	115	89	158	141	87	136

* Sample size due to listwise deletion of missing or "Don't Know" responses: Pilot N=15, Main Sample N=170.
** Pilot study contained only 5 items for C2.

Table 3.5: Internal Reliability of Factor Measures

This decision was proven successful as all but one factor in the full sample (N = 170) showed either consistency or improvement in the Cronbach's alpha. The only

exception was C1 – Flexibility in supply. Table 3.6 shows that the lack of internal consistency stems from the a significant negative correlation of C1.1 – Supply Commonality with both C1.4 – Supply Contract Flexibility and C1.5 – Alternate Sources. This appears acceptable because, for example, as the commonality of supplies increases, the number of parts required decreases and then demand pooling would dictate fewer contact changes and a more limited supplier base. It should also be noted that this factor resulted in a significant number of listwise deletions due to at least one blank or "Don't Know" entry per subject, primarily in C1.2 – Product Modularity (N = 104). Future instrument improvement may be possible.

		C1.1	C1.2	C1.3	C1.4	C1.5
C1.1	Pearson Correlation	1.000	.197**	.077	-.166*	-.273***
	N	154	101	135	119	128
C1.2	Pearson Correlation		1.000	.045	-.008	-.038
	N		104	96	84	88
C1.3	Pearson Correlation			1.000	.264***	.122
	N			140	114	118
C1.4	Pearson Correlation				1.000	.298***
	N				125	113
C1.5	Pearson Correlation					1.000
	N					133

* Correlation is significant at the 0.10 level (2-tailed).
** Correlation is significant at the 0.05 level (2-tailed).
*** Correlation is significant at the 0.01 level (2-tailed).

Table 3.6: Correlations of C1 - Flexibility in Supply (Main Sample)

Two items remain below or near the 0.5 threshold: C9 – Dispersion (α=0.461) and C3 – Capacity (α=0.515). Dispersion includes items addressing aspects of supplier, production and customer concentration, each which are independent decisions in a supply chain network. However, despite the lack of unidimensionality, we believe that the categorization maintains a logical structure that allows for the computation of an overall "Dispersion" capability score; i.e. a supply chain with dispersed suppliers, production facilities and customers will be much more capable of surviving any one localized disruption. Capacity, in a similar manner, represents multiple independent measures of capacity at the production locations: internal assets such as inventory, equipment, labor, and utilities. Although it can be argued that excess capacity of equipment must be successfully combined with sufficient reserves of labor and materials, further investigation of data leads to the conclusion that those firms concerned with redundant capacity (duplicate or redundant facilities and equipment) are also concerned with back-up, or "redundant," utilities, see Table 3.7. However, excess production capacity, which many firms reported as being cost-prohibitive, appears to be a separate dimension, which is left for further exploration.

		C3.1	C3.2	C3.3
C3.1	Pearson Correlation	1.000	.287***	.035
	N	109	97	106
C3.2	Pearson Correlation		1.000	.470***
	N		125	120
C3.3	Pearson Correlation			1.000
	N			144

*** Correlation is significant at the 0.01 level (2-tailed).

Table 3.7: Correlation of C3 - Capacity Measures (Main Sample)

The second issue was anticipated – the time required to complete the assessment. To reduce the number of questions, pilot testing determined that a high level of correlation existed between main factor question responses and the computed factor score, calculated from the average of the sub-factor ratings, see Table 3.8. Based on this analysis, two changes were made to the initial tool. Items in C2 - Flexibility in order fulfillment were modified to remove an item of ambiguity, creating an additional sub-factor (111 items). Items in C3 – Capacity were believed to be driven by C3.3 – Reserve capacity, and therefore not well correlated with the computed average score. Capacity sub-factors, as previously mentioned, will be viewed individually and as the combined factor. Therefore, to reduce the overall length of the assessment, the 21 factor questions were removed, in favor of computing the average factor score along with ranking of individual sub-factor items. In doing so, the average survey time was reduced by 4 minutes (12 percent), meeting the goal of 30 minutes (Dillman 2000).

	V1	V2	V3	V4	V5	V6	V7
Number of Items	6	6	6	6	9	5	2
Pearson Correlation, Factor Rating and Computed Factor Score	.549***	.412***	.453***	.541***	.363**	.617***	.489***
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
Number of Items	5	6	3	5	4	6	6
Pearson Correlation, Factor Rating and Computed Factor Score	.350**	.133	.185	.586***	.329**	.311*	.492***
	C8	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
Number of Items	4	5	5	6	6	6	4
Pearson Correlation, Factor Rating and Computed Factor Score	.635***	.277*	.363**	.601***	526***	.737***	.587***

* Significant at $\alpha = 0.10$
** Significant at $\alpha = 0.05$
*** Significant at $\alpha = 0.001$

Table 3.8: Correlation of Factor Rating and Computed Factor Scores, Pilot Test

Sampling Methodology

Theoretical sampling was chosen to identify firms with supply chains that are compelling examples of the target population while also providing the necessary research access (Yin 2003). As resilience is critical to all systems, the target population includes all business organizations, both for-profit and not-for-profit, global companies and privately owned small businesses, as well as corporations and governmental agencies, even though they may define performance differently (e.g. profits or services to their constituents). With increased globalization, tracing at least one raw material, purchased

component or a single customer to a foreign country is not difficult. In addition, product manufacturing tends to involve multiple firms in adding value to and transferring identifiable items in discrete units at specific times; therefore, a disruption in the flow of products (raw materials, components or finished goods) can typically be clearly identified both in time and place for study, which is typically more localized in a service industry to the point of production and therefore excluded. Therefore, the highly complex and volatile environment of global manufacturing supply chains refines the sample population to explore the various internal and external factors relating to supply chain resilience.

Sample

To ensure coverage of a wide variety of manufacturers, seven firms were identified to participate from a myriad of industries. This exceeds the minimum requirements identified by case study designers in order to reach a state of theoretical saturation (Crabtree and Miller 1999; Yin 2003). For the SCRAM™ assessment, each firm identified a sponsor from senior management to assist in selecting team members, reviewing reports and implementing selected proposals. Based on the enterprise view of the Supply Chain Resilience Framework (Pettit, Fiksel and Croxton 2008), each sponsor was requested to appoint "thought leaders" from various functions to participate: research and development, marketing, procurement, production, logistics, finance, sales, risk management, security, information technology and others as necessary. This theoretical sample is used to provide the greatest level of insight possible (Miles and Huberman 1984). A total of 170 participants participated in the seven assessments, as

shown in Figure 3.2. Company descriptions and the sanitized assessment reports are found in Appendices A-G. It is noted that Company F elected to use a reduced team size, identifying only senior-level managers from each functional specialty to capture the complete enterprise view. Finally, to improve generalizability, the sample was tested for variance in demand volatility to ensure a wide spread of market influences. Demand volatility was chosen as a primary driver of change, and as theorized by resilience, a supply chain facing higher levels of change must be more resilient to survive. Each firm in the sample is well-established having operated from 25 to 128 years (averaging 76 years). Volatility spread is shown in Figure 3.3 as calculated by each firm's primary measure of demand for the products scoped for the assessment. In a comparison to the target population, the sample firms have average quarterly revenue volatility over the past 5 quarters of 0.13 (coefficient of variation), as compared to the 18 manufacturing firms in the Dow Jones Industrial Average with revenue volatility of 0.09.

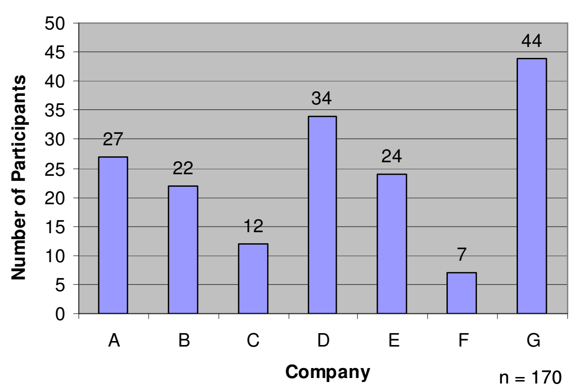


Figure 3.2: SCRAM^{TM} Participants

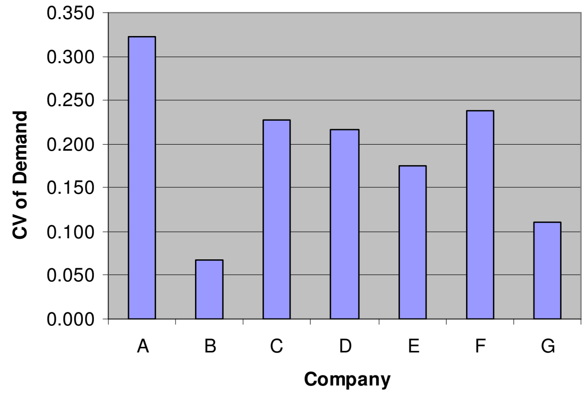


Figure 3.3: Demand Volatility in Sample

Data Collection

A secure, on-line survey was used to distribute the assessment in a user-friendly, cost-effective manner (Griffis, Goldsby and Cooper 2003). This format also improved on written surveys in eliminating the time required to transcribe responses and removing potential human errors in transcription. Format and design of the instrument used tenets of effective web-based surveys from Dillman (2000) (e.g. clear introductions, detailed instructions, parallel questions, consistent page layout, limited length and back paging). The survey instrument was reviewed and approved by The Ohio State University's Institutional Review Board.

Following the team selection at each firm, participants were provided individualized codes to prevent unauthorized access in conjunction with IP address screening to thwart ballet stuffing. All personal identifying data was removed prior to analysis to ensure confidentiality from the research team and the sponsoring firm. Participation in assessments was excellent due to the methodology of selecting a

corporate sponsor to lead the project within each firm. Following the initial assessment period, typically 2 weeks, a reminder e-mail was sent to all non-respondents. Final response rates range between 76 percent and 100 percent, with an overall response rate of 82 percent. Techniques employed to increase response rates were therefore successful, such as preliminary messages, follow-up reminders, survey sponsorship, personalization of requests, cover letters, assurance of anonymity and deadline dates (Kanuk and Berenson 1975; Lambert and Harrington 1990). Smaller firms had higher response rates, believed due to more personal contact by the sponsor at the initiation of the project. However, personal contacts by the researcher were not made and reminders were limited to a single e-mail message to prevent coercion of the respondents. Without personal contact, however, it was not possible to determine which surveys were never received (e.g. individuals not available due to vacation or out-of-town business during the assessment period), thus would have been removed from the count of potential subjects to further increase the calculated response rate (Armstrong and Overton 1977). Groves and Peytcheva (2008) list their first recommendation for reducing the risk associated with nonresponse bias is to achieve high response rates. Therefore, as all samples met or exceeded 76 percent response rate – higher than all 59 studies evaluated by Groves and Peytcheva (2008) – the affect of any nonresponse bias, if it existed, would be minimal on the larger set of respondents. Lambert and Harrington (1990) identify typical response rates between 20-40 percent in mail surveys and note that "while potential nonresponse bias should be a concern with response rates of 40 percent, it needs to be addressed with lower response rates."

Data recorded a minimal amount of blank entries, 1 percent, and a minor but expected amount of "Don't Know" responses, 10 percent. Allowing respondents to select "Don't Know" was critical in this assessment due to the breadth of the enterprise view of the Supply Chain Resilience Framework compared to the functional scope of the majority of respondents. Following responses on each of the 21 resilience factors, subjects were asked to rate the relative level of importance of each factor on a similar 5-point Likert Scale for consistency and to improve variability over a 3-point scale, using end-points of "Minor Importance" and "Critical", with the central point as "Important." These values were used in cross-tabulating the factor scores with their level of importance in order to identify priorities for managers. Average time to complete the assessment was 30.1 minutes. Administration of the assessment tool was then followed by qualitative analysis for validation using Focus Groups for data gathering.

Focus Groups

Disruptions can be classified as accidents, intentional actions or simply random events (Sheffi and Rice 2005), and a significant amount of insight on the cause of successful and unsuccessful reactions can be garnered from the organizational memory of recent, important events. "Through qualitative interviews you can understand experiences and reconstruct events in which you did not participate" (Rubin and Rubin 2005). Focus groups were guided by a semi-structured interview protocol to collect necessary data, while maintaining the highest level of reliability possible. This protocol uses probes, as applicable, to prompt the group for further explanation or more depth. In

addition, the guide allows flexibility for natural flow while assisting the moderator to keep the group on topic and cover all necessary areas (Crabtree and Miller 1999). The length of the meeting was scheduled for two hours to ensure sufficient time to fully explore the topic. "If the focus group extends beyond two hours, fatigue or disinterest may set in for both participants and moderators" Crabtree and Miller (1999). The protocol was essential for gathering a consistent set of data especially important with "heterogeneous groups, reflecting a maximum variation sample to effectively gather multiple perspectives on the topic under inquiry" (Patton 1990). And finally, Crabtree and Miller (1999) recommend designing the focus group protocol to generate discussion by subjects from multiple functions within the firm who may have different motivations, skills, experiences and outcomes; this was crucial in order to gain insight from the various perspectives required to assess Supply Chain Resilience. The Focus Group Protocol for this phase of the research is reproduced in Appendix J.

Sample

In the second phase of the study, selected firms were asked to identify recent supply chain disruptions to provide data for the qualitative validation of the assessment tool. These case studies were conducted as focus groups, interviews with a small group of individuals who were personally involved in the identification, reaction and/or resolution of the disruption. Minimum group size was two, avoiding a single biased response while encouraging more depth in responses (Goldman 1962; Morgan 1996). However, one group was conducted with a single respondent due to the company's

manpower limitations. Groups were limited to six participants to allow each individual time to provide input in an efficient manner (Crabtree and Miller 1999), with only one group drawing additional attention due to the subject matter. As with the assessment team composition, groups consisted of individuals from multiple functional areas within the firm to the greatest extent possible. Members were selected based on the sponsor's prior knowledge of the disruption under study and the critical players involved, gaining sufficient breadth of response data.

Another selection criterion for the focus group topics were the type of disruption based on the failure mode. By studying various types of disruptions, each data set will reveal new information in addition to many overlapping concepts. Despite the recognition that an infinite number of disruptive causes exist (Sheffi 2005), several authors have divided the spectrum of disruptions into categories (Rice and Caniato 2003; Hendricks and Singhal 2003; Kleindorfer and Saad 2005; Manuj and Mentzer 2008). This study therefore categorizes disruptions into the set of:

- **Supply-side disruptions:** *relating to the creation, delivery and availability of supplies when and where needed*

- **Production disruptions:** *the process of creation of products or services by the focal firm*

- **Demand-side disruptions:** *relating to distribution and sale of products to customers through to the end consumer, including additional manufacturing downstream of the focal firm*

By including multiple disruptions from each category, a more thorough data set will be gathered relative to the enterprise characteristics of the Supply Chain Resilience Framework for validation. This design is more complicated than simple multiple-case

studies because the research should still have "at least two individual cases within each of the subgroups, so that the theoretical replications across subgroups are complemented by literal replications within each subgroup" (Yin 2003). A summary of the 56 participants from 14 focus groups is listed in Figure 3.4 and Table 3.9, with descriptions of each study presented in the applicable appendix; some companies chose not to participate in the validation phase of the study.

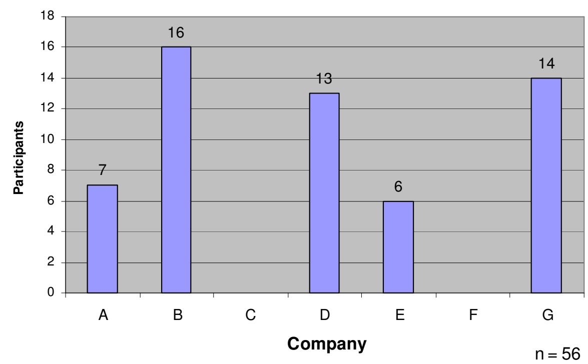


Figure 3.4: Focus Group Participants

Company	Disruption Title	# of subjects	Type of Disruption	Number of Data Items Collected
A	ILWU Lockout 2002	6	Supply-side	55
	Product Launch Overestimation	1	Demand-side	53
B	Contract Manufacturer Delays for New Product Launch	2	Supply-side	85
	Warehouse Capacity Limitations to Meet End-of-Quarter Loads	9	Operations	158
	Instability in Government Regulations in Venezuela	2	Demand-side	131
	Alignment of Revenue Forecasts with Procurement Forecasts	3	Other	42
D	Container and Transport Availability to Asia	5	Supply-side	93
	Transition of Production to New Site	5	Operations	89
	Multiple Changes in Delivery Date for Extremely Large Order by Major Customer	3	Demand-side	87
E	Instability of Product Formulation from Supplier	3	Supply-side	125
	Major Demand Changes for Promotional Item	3	Demand-side	97
G	Single-Sources Supply Failure	5	Supply-side	103
	Product Shortage	4	Operations	83
	Outbound 3PL Provider Causes Delivery and Customs Delays	5	Demand-side	168

Table 3.9: Disruption Case Studies

Instrument Validation and Reliability

"Validity is not a commodity that can be purchased with techniques" (Brinberg and McGrath 1985). However, the ideal state is to be pursed through research techniques designed into each stage of the process. Tactics to address issues such as construct validity, internal validity, external validity and reliability will be discussed.

Construct validity, ensuring operational measures are proper for the concepts being studied (Miles and Huberman 1984; Ellram 1996; Yin 2003) is controlled using multiple respondents from each of several functional areas in the firm to measure the overall level of resilience. Additionally, the sponsoring firm was requested to select participants from multiple levels of authority to gain both a tactical and a strategic perspective. A chain of evidence is maintained by the web-based server. Data is preserved with a secure database back-up and secured with encrypted transmissions and password protection. Final validation of the assessment tool was accomplished by a key informant, followed by final presentation to the firm's leadership. Therefore, multiple data sources were used to combine expert perceptions (SCRAM™ assessment) with historical performance (disruption case studies) to provide construct validity.

External validity, the extent to which the results accurately represent the phenomenon studied, thus establishing generalizability (Ellram 1996; Yin 2003), is designed into the study through a sample that includes multiple firms from the spectrum of markets. For firm selection, both product and market characteristics are expected to have a significant influence on the nature of resilience within the supply chain. The generalizability of the assessment tool is further improved as it was created using a broad set of extant literature followed by eight focus groups within a representative firm that produces a wide variety of products (Pettit, Fiksel and Croxton 2008). And finally, a set of case studies were conducted with each firm to gather historical data to compare the assessment results.

Reliability, demonstrating that the operations of a study can be repeated with the same results (Yin 2003), is controlled through a pre-test and pilot test of the assessment tool and, for the case studies, evaluated using a hold-out sample. The preliminary trials were designed to correct interpretation issues related to the format and content of the assessment tool. Five academics completed the entire assessment and provided comments to the research team. Following initial improvements, a select sample of five industry experts at Limited Brands assessed their supply chain using the on-line version of the SCRAM™ tool, including additional open-ended questions to gain their feedback on the format, readability, deployment and confidentiality of the tool. Several of these respondents provided verbal feedback to the researcher as well. By clearly defining terms and removing any ambiguity, the reliability of the instrument was improved. For the case studies, a hold-out sample for each case study was administered a subset of the focus group questions in order to evaluate the reliability of the focus group's ability to uncover the salient points. Twelve subjects were identified in the hold-out sample, typically senior leaders involved in multiple facets of the disruption being studied. These post-focus group responses recorded 119 reliability items, yielding 95 percent of common information with the focus groups and only 5 new pieces of information. Compared with the 1,369 items in the original sample, we can conclude that the focus groups performed well in extracting the necessary salient points.

Additionally, a single researcher facilitated each of the focus groups to improve consistency, and reliability of coding was assessed through blind-coding by a separate researcher (Miles and Huberman 1984). Results of blind-coding by a graduate research

assistant found 30.4 percent of vulnerabilities were like-coded while only 23.6 percent of capabilities were similar. Recurring discrepancies were noted, potentially due to the limited exposure of the assistant to the necessary concepts (only 405 items were coded versus 1,145 by the researcher), inadequate directions or language barriers. Although an initial blind-coding reliability of 60 percent is considered good (Miles and Huberman 1984), these results recommend future multiple-round coding sessions, preferably using open discussions versus blind-coding.

RESULTS AND ANALYSIS

Assessment Results

The exploratory methodology dictated review and analysis of each assessment individually and later as a whole. Following the administration of the SCRAM™ instrument, data and preliminary recommendations were presented in an open forum with the sponsor and key functional leaders from the firm. Based on confidential discussions of the data, a formal report was prepared. See Appendices A-G for non-descript assessments listed in chronological order. These discussions provided strong validation of the measurement abilities of the tool as well as conceptual linkages between the vulnerabilities and capabilities that can potentially be used to improve a supply chain's balanced resilience (see Chapter 4).

Results were presented to each firm in the form of rank order of mean factor scores based on the exploratory nature of the scale, followed by the rank order of the sub-factors. First, the seven vulnerability factors were presented with discussion of the

ratings and potentially related capability strengths and weaknesses. Overall, External pressures and Connectivity rated the highest vulnerabilities facing the firms in the sample, based on the average rank of vulnerabilities from each firm. These were followed by a mixed pattern of Sensitivity, Resource limits and Turbulence, concluding with a relatively consistent assessment of Supplier/Customer disruptions and Deliberate threats, see Table 3.10. Despite literature being dominated by case studies of weather and supplier related disruptions (Svensson 2000; Christopher and Peck 2004; Sheffi 2005), these findings are consistent with reported supply chain risks that rate infrastructure and complexity as greater threats (Elkington 2006; Craighead et al. 2007).

Ranking	Variable	Vulnerability Factor	Average rank*
1	V3	External pressures	2.0
2	V6	Connectivity	2.1
3	V5	Sensitivity	2.9
4	V4	Resource limits	3.7
5	V1	Turbulence	4.7
6	V7	Supplier/Customer disruptions	5.9
7	V2	Deliberate threats	6.7

* Using firm ranking among the seven companies in the main sample (i.e. rank 1=highest vulnerability to 7=lower vulnerability).

Table 3.10: Vulnerability Score Rankings

Similarly, each team discussed their assessed capabilities in rank order, beginning with their strengths. Again, feedback validating the assessment tool was very positive. Table 3.11 lists the overall rankings based on the average firm ranks. Market position, Recovery and Financial strengths were typically major strengths, with only a few

exceptions. It is interesting to note that many sponsors concurred with this assessment, but followed with comments such as “But these are expensive – we need to improve our anticipation and collaboration to be more competitive.” With all seven firms ranking their Collaboration at #10 or less (of the 14 capabilities), this suggests a generalizable weakness among manufacturers. It is also surprising to find that despite the high cost of investing in reserve and redundant capacity and its consistently low scores, those same firms had not created significant Flexibility in order fulfillment. On the other hand, in the instance of low reserve production Capacity, development of high levels of Flexibility in sourcing would be wasted at the production bottleneck if the supply chain is faced with a downstream disruption.

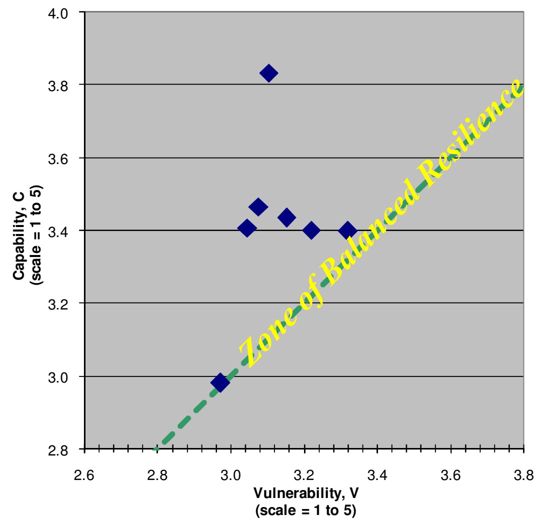
Ranking	**Variable**	**Capability Factor**	**Average rank***
1	C12	Market position	2.57
2	C8	Recovery	3.57
3	C14	Financial strength	3.86
4	C13	Security	4.29
5	C11	Organization	4.86
6	C9	Dispersion	5.29
7	C4	Efficiency	5.86
8	C7	Anticipation	9.29
9	C5	Visibility	9.71
10	C1	Flexibility in sourcing	10.14
11	C6	Adaptability	10.43
12	C2	Flexibility in order fulfillment	11.00
13	C3	Capacity	11.57
14	C10	Collaboration	12.57

* Using firm ranking among the seven companies in the main sample (i.e. rank 1=strongest capability to 14=weakest capability).

Table 3.11: Capability Score Rankings

Overall, presentation of findings at the factor level provided insight to senior managers in a strategic sense; however, they placed particular interest on the driving sub-factors in each category. A process of "drilling-down" to the sub-factor rankings was added as an interactive feature during the presentation to take advantage of this thought process and move quickly to discussion of managerially controllable items – a more tactical view.

A summary of firm assessment scores in relation to the concept of balanced resilience is shown in Figure 3.5. Clearly a cluster of firms reported similar average capabilities with varying degree of vulnerabilities. Two firms show significant variation in capability ratings, each with nearly similar average vulnerabilities. It should be noted that the sampling methodology to incorporate multiple industries in this exploratory study was chosen partially to for this reason, increasing the range of responses. Further research will evaluate the significance of this consolidated resilience assessment in relation to firm performance as previously theorized, see Chapter 4.



Note: Reduced graph scale to improve readability.

Figure 3.5: Resilience Factor Scores, Firms A-G

A closing review of the each assessment linked the factors scores with their relative importance. Areas of concern are capabilities with low scores and high importance: weaknesses that should be prioritized for improvement, or high capabilities with low importance: strengths that may be eroding profits. Although each firm was presented their own data, a compilation of priorities for the seven companies are shown in Figure 3.6 and Figure 3.7. For vulnerabilities, firms reported a general balance between the assessment score and the importance score, with the exception of Supplier/Customer disruptions and Resource limits. It would seem that the firms in this limited sample have selected reliable suppliers and customers as a critical aspect of supply chain resilience, thus reporting low scores while confirming the importance of supply chain continuity. In addition, these firms reported only moderate Resource limits while confirming its relative importance as a critical aspect to creating supply chain

disruptions. Again, we theorize that the well-established firms in the sample have created a solid resource base given their business environment.

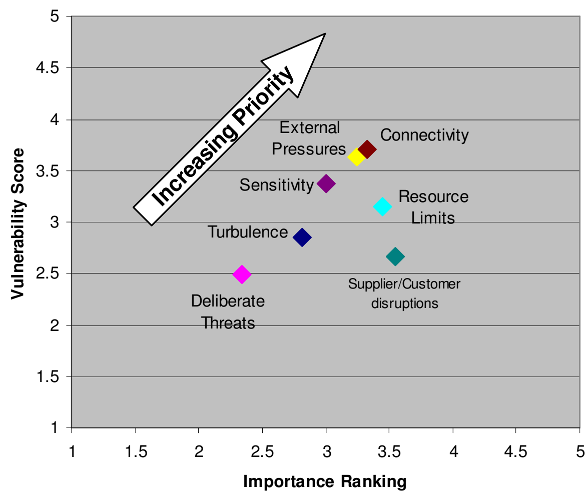
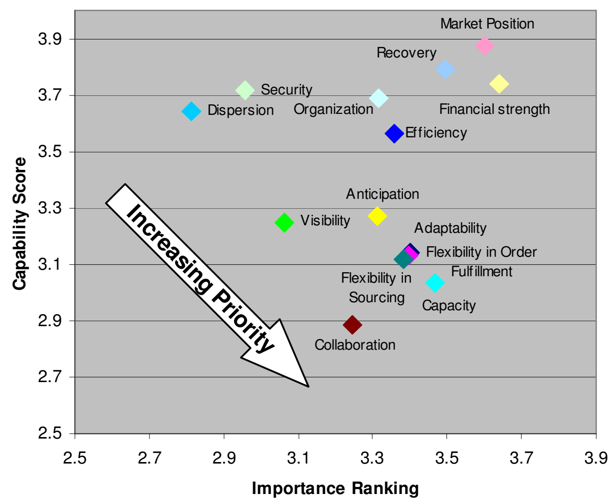


Figure 3.6: Prioritization of Vulnerabilities



Note: Reduced graph scale to improve readability.

Figure 3.7: Prioritization of Capabilities

Validation Results

A total of 14 disruption focus groups were conducted to validate the Supply Chain Resilience Assessment and Management tool, SCRAM^{TM}. Several focus groups were conducted in-person, while others were conducted via teleconference primarily to simultaneously link participants in multiple locations, including North America, Asia, Europe and South America. Average focus group length was 2.1 hours, recording 1,369 line items of data through transcription using a descriptive coding design (Miles and Huberman 1984). Each line item was then coded in an interpretive process to assign each item with vulnerability and/or capabilities categories, as appropriate. Many items were ignored in this process as they were merely informational in nature, such as general production information, dates and locations. Interpreted items were coded as positive if representing a strong capability or high vulnerabilities, or coded as negative if representing a weak capability or low vulnerability. Several items were coded in multiple categories if appropriate. For example, if a weather disturbance caused an ocean shipment to miss its booking which caused further delays due to lack of ocean freight capacity, this item would be coded for positive Turbulence (V1) for the weather and positive Resource Limits (V4) for the lack of distribution services. See Table 3.12 for summary statistics of focus group data.

	Firms	Focus Groups	Subjects	Number of Data Line items	# of Positive Coded Items	# of Negative Coded Items
Total	5	14*	56	1,369	805	340
Average per Focus Group			4.0	97.8	57.5	24.3
				Vulnerabilities	459	11
				Capabilities	315	315

* One item was taken from a separate Case Study recently accomplished by the research team. The topic was validated as a critical disruption by the firm's leadership, and Focus Group Protocol responses were taken from the case study notes and report, sufficiently addressing all areas.

Table 3.12: Validation Data Summary

The chosen methodology was very successful in exploring these complex issues through a combination of detailed and open-ended questioning. Coding revealed a good mix of positively coded items and negatively coded items. However, as the focus groups were investigating actual disruptions, events that interrupted operations in some way, very few low vulnerabilities were discussed, as expected. On the contrary, a good variety of capabilities were coded implying that the focus groups conveyed their supply chain's strengths as well as their weaknesses. Including participants with multiple functional roles was extremely beneficial is moving beyond the primary cause of, and response to, the disruptions being studied. For example, in one session the opening discussion revolved around a single-point failure in production machinery while further exploration uncovered disagreements between production leadership and planners to yield new inputs on multiple recovery efforts, miscommunications on repair priorities and complex

interconnections between other plants and products. Another group spurred a discussion between the sales manager and the logistics manager on current recovery plans, actually resolving a misinterpretation of the sales manager's directions from earlier in the day, thus during the focus group authorizing the logistics manager to ship product that was on-hand and difficult to store. Examples of interpretive coding are listed in Table 3.13.

Variable	Capability Factor	Code	Example from Coded Data
C1	Flexibility in sourcing	+	Containers are common to several products with unique labels printed during fill process.
		-	Contracts include fees to change delivery date or quantity.
C2	Flexibility in order fulfillment	+	Transportation sourced through a 3PL provider to several carriers.
		-	Cannot pool customer demand due to unique packaging requirements for each.
C3	Capacity	+	Redundant production streams for process #1 allowed for continued operation while stream A repaired.
		-	Demand is strong, exceeds capacity to produce.
C4	Efficiency	+	Normal process is very efficient, with little manual intervention.
		-	Significant down-time planned into production schedule.
C5	Visibility	+	Accessed customer's order system directly to immediately freeze orders until production resumed.
		-	We didn't even tell our logistics managers what the real problem was.
C6	Adaptability	+	Two years ago competitors left this market due to high risks; we have significantly grown sales.
		-	A couple of years ago the idea was discussed to change our incentive system, now we finally understand how important the change is.
C7	Anticipation	+	Our contingency plan had this event covered.
		-	Leadership's direction was to reduce the amount of owned rail cars; didn't anticipate increased sales and market capacity constraining which reduced ability to lease rail cars.
C8	Recovery	+	We purchased product from local competitors to fill orders on-time, despite the cost.
		-	Testing reveled initial signs of product degradation, but information for not shared or acted upon.
C9	Dispersion	+	Our customers are evenly spread around the world.
		-	Two-thirds production is in one plant, other facility is 200 miles.
C10	Collaboration	+	Our major customer appointed a local customs broker to exclusively handle our shipments.
		-	We get very little help from our supplier; they and not proactive.
C11	Organization	+	Our new division has much less corporate micro-management, but we are accountable for our performance.
		-	We have lots of personnel turn-over.
C12	Market Position	+	Our customer was satisfied because we informed them immediately about the disruption and detailed our recovery plan with them.
		-	Our customer segmentation matrix has not been updated in over 2 years; over 80 percent of customers are in category 1 (of 4).
C13	Security	+	We add contracted security to shipments in particular regions.
		-	When orders do not ship immediately, storage capacity is so tight that inventory is left on the floor and becomes a liability due to theft.
C14	Financial strength	+	We have financial reserves to hire temporary workers to meet end-of-quarter surge demands, despite 50 percent of total labor cost is in training.
		-	Emergency outsourcing dramatically reduced our price margin.

Table 3.13: Focus Group Codings, Capabilities

Qualitative evaluation of the assessment tool's construct validity was evaluated using these interpretive codes. Positive and negative codes were summed for each factor in the Supply Chain Resilience Framework and compared against the firm's assessment results. The factor scores from the assessment were used as a basis due to the Likert scale with a neutral response, "Neither agree nor disagree," as a score of 3.0. Therefore, a score of greater than 3.0 indicates some level of agreement, even though the absolute scale has not been empirically validated in a large study. As very little data was gathered for low vulnerabilities, direct qualitative comparisons were used to establish construct validity through example, to be discussed later.

For the 14 capability factors, a binary decision criterion was chosen to validate a capability factor's construct, for factors scoring above 3.0, was if the number of positively coded items exceeds the negatively coded items. Correspondingly, empirical data validated a factor's construct for factors scoring below 3.0 if the number of negatively coded items exceeds the positives. If the positive and negative examples were equal in number, no determination was made for that factor. No scores of 3.0 were noted. Using the number of firms that validated each capability score, a 92.9 percent validation rate was computed; see Figure 3.8 for an overview of the capability results.

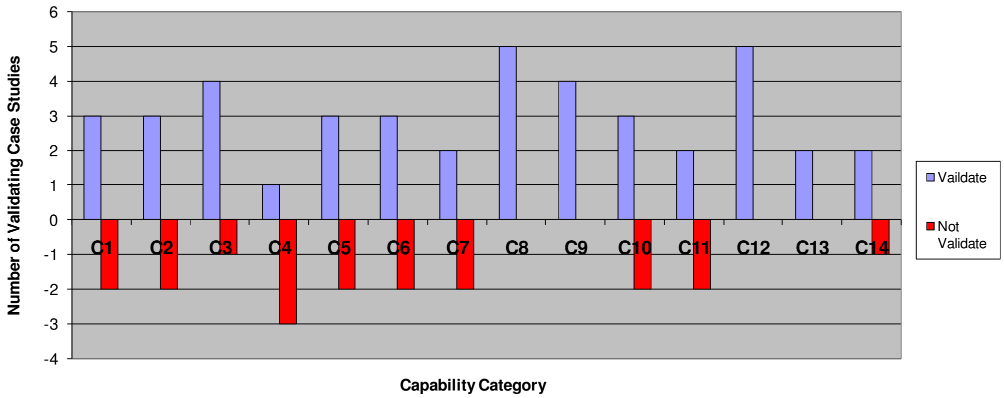


Figure 3.8: Capability Validation

Only one capability factor of the 14 was not validated using this methodology. Efficiency (C4) was reported low by two of the three firms with interpreted codings in this area. Both of these firms assessed their Efficiency has high (i.e. above 3.0 threshold), averaging 3.66. This result is acceptable as validation data on actual disruptions found primarily negative examples of reliable equipment and asset utilization, which are biased due to the sampling method (e.g. unreliable equipment as a contributing cause of the disruption).

Although four of the seven vulnerability factors are validated using the previous technique (Figure 3.9), construct validity for vulnerabilities can also be determined through direct application of the case study responses for each of the seven vulnerability factors. See Table 3.14 for examples of positive and negative codings, with a summary shown in Figure 3.9 based on the comparison to factor scores at the 3.0 "Neutral" threshold.

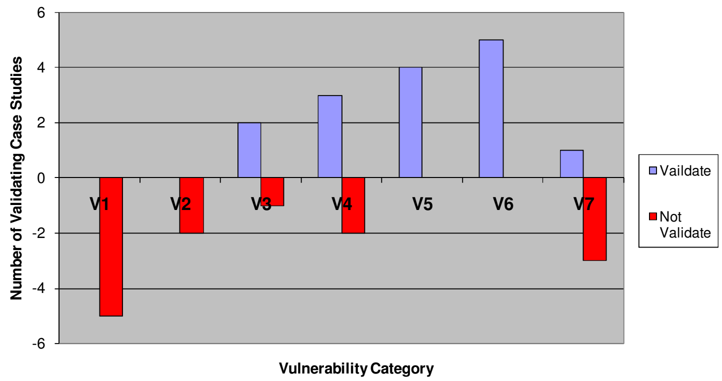


Figure 3.9: Vulnerability Validation

First, Turbulence (V1) was reported below 3.0 for each of the five firms in the validation phase (i.e. assessment respondents "disagreed" to some level with the vulnerability statements). Although these firms may experience an overall level of moderate turbulence (average of 2.75), the 14 case studies all reported some examples of high turbulence. Examples of turbulence were uncovered in each of the six sub-factors except natural disasters and pandemics, although the latter was of major concern to three of the firms with overseas production or stateside emergency response functions. The subject of natural disasters is well documented and not a concern of missing data due to the nature of the studied disruptions.

Variable	Capability Factor	Code	Example from Coded Data
V1	Turbulence	+	Forecast error (MAPE) for this product is very high, about 50%, as compared to other items with 13-15% error.
		-	Overall demand was as planned.
V2	Deliberate Threats	+	Attempted theft of product from warehouse was thwarted but a sign of the threat.
		-	None.
V3	External Pressures	+	Saw an increase in competitor offerings 1-year after our launch, followed soon by generic and retailer-branded items.
		-	None.
V4	Resource Limits	+	Availability of ISO containers for outbound shipments is severely constrained.
		-	Supplier's production plant was operating at 50 percent capacity.
V5	Sensitivity	+	R&D has review substitute inputs, however significant changes to the production process would be required based on the specific characteristics of each version.
		-	Equipment is reliable and easily repaired.
V6	Connectivity	+	Transportation to the Pacific involves container supplier, 3PL, vessel operator, import/export customs, receiving broker and financial clearing house.
		-	None.
V7	Supplier/ Customer Disruptions	+	In March 2008, no orders were received at all due to this issue.
		-	None.

Table 3.14: Focus Group Codings, Vulnerabilities

Deliberate threats (V2) comprise a list of very specific threats to a supply chain. Examples validating this factor were limited due to the disruptions selected. Sub-factors of theft and union activities were examples of positive vulnerabilities discussed by the focus groups. These two firms scored Deliberate threats (2.82) higher than the three firms that did not select disruptions attributed to these types of attacks (2.70), providing a positive validation of the assessment tool.

External pressures (V3) similarly includes a very descriptive list of sub-factors. Only two firms reported focus group items coded in this area, both examples of high vulnerability in the areas of competitive pressures and government regulations. Again, the average assessment of External pressures by these two firms (3.87) was higher than the three firms (3.63) that did not select examples of threats from External pressures.

Resource limits (V4) recorded 106 items from the focus groups, all but three as positive examples of resources threatening operations. All three firms scoring Resource limits above 3.0 provided multiple examples in this category, averaging 26.3 examples of Resource limits per firm as compared to only 13.5 examples per firm for the firms rating V4 below the 3.0 threshold. Examples were given in all sub-factors except "utilities availability," which is described in several examples in literature, thus providing evidence to support the assessment tool in this area.

Sensitivity (V5) revealed 67 examples of threats from sensitivity and only three examples of low sensitivity. Four of the five firms reported examples of high Sensitivity, all four scoring well above the 3.0 threshold of high vulnerability. The one firm that did not discuss sensitivity issues assessed their vulnerability lower (3.02) than the other four companies (3.38). Focus group responses covered all nine sub-factors. Therefore, this factor and its nine sub-factors are important measurements of vulnerability.

Connectivity (V6) was a frequently discussed category during the focus groups from all firms, coding 99 positive items and only two negative items. All of the five sub-factors were covered multiple times. Validating this finding is the average score of V6 for the five firms participating in the focus groups of 3.98, the highest of all seven

vulnerability factors. The most frequently cited issue was the scale and extent of the supply chain network, expected as the sampling methodology required participation from global firms. These vast supply chains require large amounts of information flow (second most reported item) and many import/export nodes (third ranking). These points taken together strongly validate the assessment tool in the area of Connectivity.

Supplier/Customer disruptions (V7) was expected to be well reported in the supply-side and demand-side disruptions. In all, 41 examples were provided between the 14 case studies. The only firm that did not report examples of supplier or customer disruptions rated V7 at 2.25, lower than all of the other firms that discussed supply chain partner reliability, with an average score of 2.72. Two firms rated low threats from these disruptions (2.41), while still reporting several examples during the focus groups, potentially due to selection bias. As was suggested in Pettit, Fiksel and Croxton's work (2008), the assessment questions in this area may be lacking in depth. Potential improvements may be found by expanding the subjective questionnaire, obtaining objective data on past reliability of key suppliers and customers, or implementing the entire assessment at multiple tiers of the supply chain. The latter would be designed to directly assess the resilience of each member of the supply chain and then integrate the results into a holistic measure of resilience. Relative similarities, differences and specific factor scores could be used to strategically build resilience into various tiers directly based on comparative vulnerabilities. These efforts remain for future research.

CONCLUSIONS

The Supply Chain Resilience Assessment and Management (SCRAM^{TM}) tool proved to be a valid method of evaluating the current level of resilience of a firm. Presentation of results to corporate sponsors and their functional leaders provided excellent feedback as to the breadth of the Supply Chain Resilience Framework and the ability of the SCRAM^{TM} tool to accurately measure the sources of change facing the firm as well as the firm's strengths and weaknesses. By analyzing results from seven firms with global manufacturing supply chains, it was found that External pressures and Connectivity are the highest vulnerabilities facing this diverse group of companies. Although the firms in the sample reported relatively low threats from Supplier/Customer disruptions, data validated previous studies by placing the highest importance on these issues impacting the supply chain.

Firms in this study reported capability strengths in the areas of Market position, Recovery and Financial strengths. However, consistent reports of low Collaboration, lack of excess Capacity and minimal Flexibility raised serious concerns to the corporate sponsors. When highly rated vulnerabilities were discussed in relation to potentially linked weak capabilities at a strategic level, sponsors were compelled to action, requesting more detailed comparisons to provide tactical recommendations to improve their resilience within the fitness space to best match the Zone of Balanced Resilience. Overall, feedback from these sponsors and validation through a series of focus groups concur that SCRAM^{TM} is a valuable tool for providing insight into a supply chain's level of resilience.

RECOMMENDATIONS FOR FUTURE RESEARCH

Several concerns were noted during this research and presented here for future research. First, as the prioritization of capability scores versus importance, Figure 3.7, on average showed Security and Dispersion as potentially eroding profits, this phenomenon may be an artifact of successful security programs and dispersion decisions, lowering the perception of relative importance. Next, larger scale implementation is necessary to validate the measurement scales, identifying critical zones and clusters, see Figure 3.1. To improve the instrument itself, the process of interpretive coding for this study resulted in 17 items to be considered for future refinement of the assessment tool, such as potential overlap in categories, new sub-factors and alternate question wording. Refinement and replication of the categorization of items in the Supply Chain Resilience Framework may improve unidimensionality of the resilience factors and validate the generalizability of the framework and tool. Factor analysis can be accomplished to further explore and eventually confirm the underlying dimensions of resilience. Also, future research may determine multiple measures at the sub-factor level, with the addition of objective measurements where appropriate. As these measures become more specialized, it may be necessary to create industry-specific items or even firm- or product-level assessment items. And as mentioned previously, assessment of Supplier/Customer disruptions (V7) may need to be expounded or a methodology developed to implement the SCRAM™ tool as various tiers of the supply chain and integrate the results.

Two elements remain to complete the exploratory stage of this research. First, an empirical study is needed to test the relationship between increased resilience and the ability to predict and react to change, see Proposition 3C. Second, empirical evidence is required to support management change efforts based on the results of the SCRAM™ assessment through discovery of linkages between each vulnerability and a specific set of capabilities that can directly improve balanced resilience, see Proposition 2.

As the current scope of the Supply Chain Resilience Framework is based on resilience in the context of ensuring operational business continuity, a broader extension to include strategic sustainability can yield further insights. Managers in a strategic role are concerned with longer planning horizons with focus on both financial and social responsibilities. Now that we can measure the current state of supply chain resilience, the next step is to refine the process of integrating the vision of resilience into our organizations. The final barrier to resilience is ideological (Hamel and Valikangas 2003). Educating corporate leaders on the concept of resilience and providing tool such as the Supply Chain Resilience Assessment and Management, SCRAM™, will greatly enhance current risk management strategies to allow supply chains to survive, adapt and grow in the face of turbulent change.

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CHAPTER 4

IDENTIFICATION OF CAPABILITY LINKAGES

INTRODUCTION

Supply chain resilience provides great promise as a complement to traditional risk management techniques in dealing with uncertainty and change that is inevitable in the complex, competitive business environment. Studies have shown that many businesses are unprepared to handle adverse events while crisis-ready companies gain a competitive advantage (IOMA 2008). Resilience is not only a concept for reacting to disasters, but Flynn (2008) asserts that the economic benefits of resilience are realized daily since "virtually all of the attributes it takes to make a resilient company are things that make a company work better in the first place." However, this state of resilience is not merely a static state to be achieved but an on-going process due to an ever changing, uncertain world.

The process of ensuring supply chain resilience begins with identifying the desired state within the resilience fitness space proposed in Chapter 2, which then can be compared with the firm's "as-is" state as measured through the Supply Chain Resilience Assessment and Management (SCRAM^{TM}) tool in Chapter 3. This chapter will continue to develop the resilience management process by empirically verifying the proposition

that increased resilience improves performance. Then, by identifying capability linkages that have direct affects on specific vulnerabilities, supply chain leaders can utilize this information to manage purposeful change toward achieving their desired state of resilience. By undertaking this process, firms can create a portfolio of capabilities best matched to their pattern of vulnerabilities in order to position and maintain their supply chain in the desired state of balanced resilience. The following sections provide a brief literature review of resilience tenets, a description of the methodologies utilized, a presentation of the analysis and conclude with results and implications.

LITERATURE REVIEW

Despite the surge in the use of the term resilience in supply chain management, there remains a lack of an accepted definition and even less agreement as to the factors that contribute to resilience. Flynn (2008) defines resilience with the "four R's" – robustness, resourcefulness, recovery and review. Rice and Caniato (2003) and Sheffi (2005, 2008) focus resilience on redundancy and flexibility, recommending leaders to develop a "flexibility DNA" through communicating, distributing authority, developing a passion for the mission, deferring to experience and conditioning for disruptions. Although a feedback cycle implies a learning and modification process, a resilient organization designs appropriate levels of anticipation, preparedness and adaptability, in addition to reactionary skills, that is essential to creating a competitive advantage.

The finance and economics domains are well experienced with this requirement to anticipate change and have more appropriately combined this adaptive capacity into their

definition of resilience. This is critical with the responsibilities of supply chain managers to ensure both short-term continuity and long-term profitability and growth. McCullough (2008) points out that "the collaborative and innovative nature of [the financial services industry] has enabled us to not only endure rocky periods but become stronger because of them." This is also true in the ecology field where Perrings (2006) points to two main attributes of resilience: robustness and adaptive capacity. In a competitive marketplace, it is essential that the ability to return to normal operations be combined with a complementary ability to learn and change when necessary. In the business literature, Hamel and Valikangas (2003) captured this essence in their definition of resilience: "The ability to dynamically reinvent business models and strategies as circumstances change." Fiksel (2003, 2006) incorporates these views to define resilience as "the capacity of an enterprise to survive, adapt and grow in the face of turbulent change." Adopted by the Council on Competitiveness (2007), this definition is preferable to the engineering concept that limits resilience to returning to its original form. Supply chains must adapt to their environment as well as their own innovations. This chapter presents results that will provide supply chain managers with direction to assist in their resilience improvement process – "resilience is the ability to know where, how and when to use your energies to improve" (Daniel 2003).

METHODOLOGY

This phase of the research is divided into two distinct sections: empirical testing of the resilience construct followed by a detailed series of analyses to uncover critical

linkages between managerial capabilities and supply chain vulnerabilities that can be used to improve resilience and therefore long-term survival and growth.

Does Resilience Improve Performance?

To begin the analysis, the construct of resilience will be empirically tested. The initial research proposition from Chapter 2 stated that "supply chain resilience improves as capabilities increase and vulnerabilities decrease" – higher resilience will allow a supply chain to better anticipate, react and adapt to the changing environment, thus improving performance. We postulate by definition that improved performance due to resilience will in the short-term result in lower performance volatility. For example, an extremely resilient supply chain will always meet customer demand at each tier through to the end consumer and will always be one-step ahead of the competition to meet consumer needs – just as the customers themselves realize their own needs. In this hypothetical extreme, the highest state of resilience is a very expensive proposition even in high-margin markets; however, performance in this case will be theoretically constant, leading to zero performance volatility.

As this study is exploratory in nature, data from the seven firms participating in this round of SCRAM™ assessments will be used to extract inferences on the potential relationship between resilience and performance. As large samples are gathered, more detailed hypothesis testing can be accomplished to directly address the research propositions of Chapter 2.

The Application of Mixed-Methods to Improve Resilience

Knowing your current state of resilience is only the first step – managers need reliable advice on how to improve their resilience in order to meet corporate strategies for survival and long-term grow. As the Supply Chain Resilience Framework treats vulnerabilities as fixed in the short-term as inherent characteristics of the supply chain environment, managers require evidence of linkages between their vulnerabilities that they need to mitigate and the capabilities that they can directly control. Based on the breadth of the Supply Chain Resilience Framework, this is a very complex task. Editors of the *Journal of Operations Management* recently asserted that "it is our strong belief that multiple approaches are required in order to develop a holistic understanding of operations and supply chain management phenomena" (Boyer and Swink 2008). Therefore, the proper methodology to conduct exploratory research is not always a single method proven through past experience, but can be a series of methods chosen based on the extant theory, data sources and objectives of the research and results combined in a logical progression to reach a convergence.

Research methods in business management can be categorized by the method of data acquisition: theoretical, survey-based, case study-based and experimental. This section will discuss a mixed-methods approach that combines the first three categories, ignoring potential application of controlled experiments that are all but impossible in the business arena in full-scale implementation due to cost, time and influence on the system itself. Supply chain simulations attempt to overcome these barriers of experimentation, but add limitations from simplifying assumptions, condensed scope and dependence on

historical data to estimate probability distributions (Chatfield, Harrison and Hayya 2006). Once resilience theory develops sufficiently to provide the necessary modeling inputs and assumptions, this tool will become very useful.

When applicable methods are applied with a variety of data, the convergence of multiple methods provides additional validation (Jick 1979). A recent surge in mixed-methods research has proven the applicability of these types of triangulation techniques, with 53 percent of articles reviewed from the year 2004 using mixed-methods (Frankel, Naslund and Bolumole 2005). Therefore, this phase of the exploratory research combines theoretical perspectives, quantitative methods and qualitative interpretation of empirical data to triangulate these three methodologies to improve the confidence in the resulting resilience linkages.

Theoretical Linkages

During the first phase of this research, extant literature was consolidated and combined with insightful anecdotal evidence from practitioners (see Chapter 2), building the researcher's baseline understanding of the concepts involved that is necessary to theory construction (Yin 2003). Following eight on-site focus groups to categorize the 21 factors and 111 sub-factors of the Supply Chain Resilience Framework and discussing the results of seven Supply Chain Resilience Assessment and Management (SCRAM^{TM}) surveys with each firm's leadership, potential linkages were theorized by the researcher. This concept is validated by a recent investigation of published logistics research, which concluded that significant contributions can be made "by the researcher spending time in

organizations and observing and/or communicating with professionals performing logistics in action" (Frankel, Naslund and Bolumole 2005). This initial set of potential linkages is clearly biased by the researcher's knowledge, experience and deductive reasoning. Therefore, triangulation with empirical data searches for the confluence of conclusions will determine more stringent results.

Correlation of Survey Responses

Second, survey data was gathered in Phase II of this study as presented in Chapter 3 as a low-cost, non-invasive method for gathering expert perceptions on complex issues that may not be readily identified by objective measures. Multiple respondents from critical functional areas within the firm reduces individual bias while efficiently encompassing the breadth of issues relating to supply chain resilience. The format also allowed for expeditious consolidation by functional area, managerial level and as a whole, which provided many significant inputs to the participating firms. In this step of the methodology, statistically significant correlations between vulnerability scores and capabilities scores are desired. From an exploratory perspective, this study does not attempt to define or predict the relationships or the direction of the relationships. For example, firms in the sample may employ well balanced resilience in a particular area by design and therefore these vulnerabilities will be positively correlated: low vulnerabilities matched with low capabilities, high vulnerabilities with high capabilities. A specific scenario observed during this research was that firms facing severe threats from competitive innovation have developed strong capabilities in information exchange

between supply chain members as well as effective business intelligence programs, whereas the reverse is true for firms with low competitive innovation threats. However, in other areas, the sample firms may not have developed a well balanced portfolio of capabilities due to externally controlled factors, superseding priorities, lack of understanding of the issues or other causes. In this circumstance, a negative correlation between the vulnerability and capability will be present. For example, in a low-turbulence environment a firm should be able to very efficiently employ their equipment and labor resources. In contrast, a highly volatile supply chain requires excess manufacturing capacity, frequent unscheduled production change-overs and/or large amounts of inventory to buffer production from demand. It should be noted that the absence of a significant correlation does not by itself negate the possibility of a linkage existing, only that the firms in the limited sample did not assess the relationship similarly. In addition, testing of these specific associations must be left for further studies incorporating performance measures directly associated with each linkage; however, through the use of moderately stringent confident intervals (α=0.10) and the triangulation methodology employed, results will distill in the confluence of theory and empirical evidence.

Pattern Matching of Focus Group Responses

And finally, focus groups are an excellent source of qualitative data when exploring complex issues (Morgan 1996). Case or field-based studies provide a qualitative approach to studying a phenomena in-depth, particularly poorly understood or

emerging phenomena. Primarily used as a theory-building approach, case studies have been effectively employed in a large variety of situations and are excellent guides for conducting research in both the broader business environment (Eisenhardt 1989; Yin, 2003) and the operations management literature (McCutcheon and Meredith 1993; Meredith 1998; Craighead and Meredith 2008). Benefits of case studies include the ability to examine a topic in great depth, and researchers can focus on a specific topic or company, allowing a thorough examination of numerous factors and nuances. Case studies provide a richness of description and firsthand observation of phenomena in a natural setting that often yield unintended insights, which can lead to new avenues of inquiry. The best case studies provide a foundation for further examination. Limitations of case studies include cost and time, inability to generalize and prescribe, and potential for bias in the perceptions of the researchers (Boyer and Swink 2008).

Recent case study research proves that qualitative methodologies can be as useful and as rigorous as other research methods, and if triangulated with quantitative methods leads to improved theory development (Frankel, Naslund and Bolumole 2005). Quantitative methods alone frequently do not capture the complex interactions of the business environment, organizational issues and societal culture (Kiessling and Harvey 2005). Therefore, this study's comparison of theoretical data, survey data and case study data creates a mixed-methods approach to produce results with the required depth and breadth.

Using the 1,369 line items from the 14 focus groups discussed in Chapter 3, additional analyses were performed to uncover empirical correlations between

vulnerabilities and capabilities. Pattern matching was used to determine connections between main factor variables based on the set of qualitative data. Given the sampling methodology of selecting firms from heterogeneous industries and conducting multiple focus groups at each firm – supply-side, operations and demand-side disruptions – a broad selection of unique examples can be used to cover a wide breadth of the topic (Miles and Huberman 1984). Comparing this matrix of linkages allows for three separate two-way comparisons and a final three-way confluence of linkages, as presented in the following section.

RESULTS AND ANALYSIS

Influence of Resilience on Performance

Following data collection and validation in Chapter 3, analysis begins with assessing the impact of resilience on performance for the firms within this exploratory sample. To accomplish this, an operational versus strategic view of resilience will be used with successful performance measured by the firm's ability to maintain consistent performance metrics. Therefore, improved performance would be manifested in reduced variability in key performance metrics. The converse is that firms with lower levels of resilience will be repeatedly hampered by disruptions, for example stock-outs followed by overstocks, resulting in high metric volatility. This measurement of resilience, in contrast to the concept of balanced resilience as presented in Chapter 2, does not take into account the investment required to implement or maintain specific capabilities, only the

resulting effects. Evaluation of strategic resilience considering long-term profitability and growth aspects will be addressed in future research.

Using the Supply Chain Resilience Framework, resilience can be computed using the two-dimensions of vulnerabilities and capabilities in accordance with Proposition 1, shown in Figure 4.1. The calculation of a resilience score, R, is based on a firm's average vulnerability score, V, and the average capability score, C, as given by $R = \frac{C - V + 4}{8}$ when utilizing the Likert Scale of 1-to-5 employed by the Supply Chain Resilience Assessment and Management (SCRAM^{TM}) tool. Construct scores can be computed by averaging the factor scores, assuming equal weights for each factor, in the manner of $V = \frac{\sum_{i=1}^{n_V} V_i}{n_V}, n_V = 7$, and $C = \frac{\sum_{j=1}^{n_C} C_j}{n_C}, n_C = 14$. Factor scores come directly from the assessment tool by averaging the associated sub-factors in a similar manner, again assuming equally weighted items, as $V_i = \frac{\sum_{k=1}^{n_{V_i}} V_{i,k}}{n_{V_i}}, i = 1 \rightarrow n_V$, where n_{Vi} varies with the number of items in the ith vulnerability factor and $C_j = \frac{\sum_{k=1}^{n_{C_j}} C_{j,k}}{n_{C_j}}, j = 1 \rightarrow n_C$, where n_{Cj} varies according to the number of items in the jth capability factor. Sample values of resilience, R, are shown on Figure 4.1 along with gradient lines at R = 0, 25, 50, 75 and 100 percent.

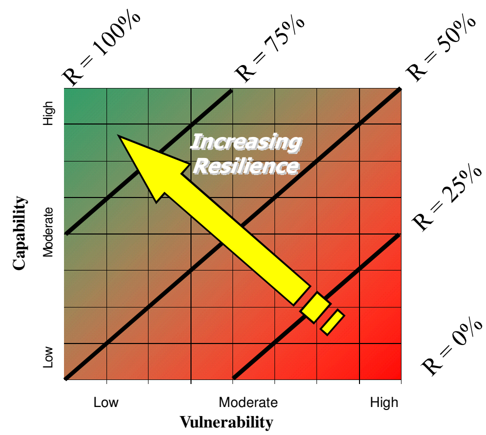

Figure 4.1: Resilience Computation

Representing the volatility of performance, the standard deviation of performance metrics is used to measure the variation around the mean. In order to compare multiple metrics, each targeting a separate dimension of supply chain operations, the coefficient of variation, CV, is an appropriate measure of the volatility for cross-comparison. CV is defined as the ratio of the standard deviation to the mean, therefore a dimensionless number to allow comparison of the variation of metrics that have significantly different mean values. However, when the mean value is near zero, the coefficient of variation is overly sensitive to change in the standard deviation. In this study, each participating firm provided between three to 12 performance measures, covering the period of assessment and one year prior to the assessment, that were currently being employed as their most critical measures of operational performance. Examples include availability, delivery lead-time, inventory position, order accuracy and customer complaints. Combining these

metrics computes an overall measure of the firm's performance volatility, the coefficient of variation for performance, CVP.

Exploratory data from this study is compared in terms of firm resilience and perfromance as shown in Figure 4.2. Firms in this initial sample reporting higher resilience scores reported lower volatility of supply chain performance metrics. Firms in the sample with lower resilience scores demonstrated higher volatility in performance metrics, thus inferring that there is a potential for performance gains due to improved resilience. One may note that the range of resilience scores is narrow and clustered toward the center of the scale. This may very well be a result of the well-established companies who have invested in resilience-type programs to stay competitive. Although the small sample here does not define the Resilience Fitness Space, Figure 2.4, the data does not refute Propositions 3a and 3b from Chapter 2 in that firms are not expected to exist in the lower-left (over-exposure to risk) or upper-left (erosion of profits) and therefore successful firms would potentially be clustered along the Zone of Balanced Resilience.

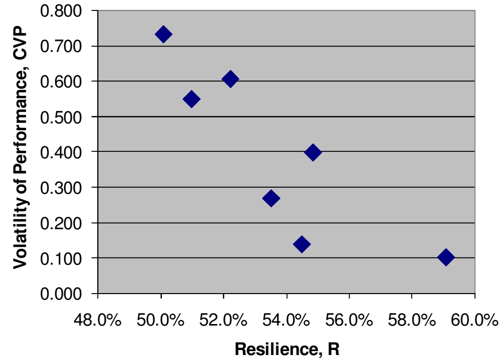

Figure 4.2: Resilience Inference on Performance Volatility

Critical Linkages between Vulnerabilities and Capabilities

Triangulation of two or more methods can capture a more complete, holistic and contextual portrayal of the units under study (Jick 1979). In this effort to establish the confluence of these methodologies: theoretical linkages, highly correlated variables and case study connections, a highly reliable set of vulnerability-capability linkages can be determined. Managers can then use these exploratory results in conjunction with the SCRAM™ assessment results to manage their portfolio of capabilities based on the level of inherent vulnerabilities in their supply chain. Thus, change can be controlled within the fitness space of resilience with the goal of maintaining balanced resilience throughout the turbulent future.

Results of this triangulation are encouraging. At the factor level, the researcher identified 45 linkages, correlations of SCRAM™ data revealed 20 potential linkages (α = 0.10) and focus group responses identified 70 linkages. Table 4.1 summarizes the comparisons between these potential linkages using two-way and three-way comparisons.

For maximum validity, the confluence of all three methods is desirable; however, the absence of results from a single method does not negate a potential linkage. Therefore, balancing the desire to create a reliable list of potential linkages with the exploratory goal of identifying all possible linkages for managers to consider when developing or modifying their portfolio of capabilities, Table 4.2 lists the two-way and three-way triangulations by vulnerability factor.

One-way Comparisons	Two-way Comparisons	Three-way Comparisons	Number of Linkages*, **
1) A or B or C			83
	1) A and B		9
	2) A and C		37
	3) B and C		15
	Two-way links		43
	Two-way links not three-way links		34
		1) A and B and C	9

A = Theoretical Linkages, B = Survey Correlations, C = Focus Group Connections
* Maximum possible linkages = 7 vulnerabilities x 14 capabilities = 98.
** $\alpha = 0.10$ for correlations.

Table 4.1: Summary of Factor-level Linkages by Methodology

Vulnerability Factor	Linked Capability Factors
Turbulence (V1)	• Flexibility in Sourcing (C1) * • Flexibility in order fulfillment (C2) * • Capacity (C3) * • Visibility (C5) ** • Adaptability (C6) * • Anticipation (C7) * • Recovery (C8) * • Dispersion (C9) * • Collaboration (C10) **
Deliberate threats (V2)	• Adaptability (C6) * • Anticipation (C7) * • Recovery (C8) * • Security (C13) *
External pressures (V3)	• Adaptability (C6) *
Resource limits (V4)	• Flexibility in sourcing (C1) ** • Flexibility in order fulfillment (C2) * • Capacity (C3) ** • Efficiency (C4) * • Adaptability (C6) * • Anticipation (C7) * • Dispersion (C9) * • Market position (C12) * • Financial strength (C14) **
Sensitivity (V5)	• Efficiency (C4) * • Adaptability (C6) * • Dispersion (C9) *
Connectivity (V6)	• Flexibility in sourcing (C1) ** • Flexibility in order fulfillment (C2) * • Visibility (C5) ** • Adaptability (C6) * • Anticipation (C7) * • Collaboration (C10) * • Organization (C11) * • Market position (C12) * • Financial strength (C14) *
Supplier/Customer disruptions (V7)	• Flexibility in sourcing (C1) ** • Flexibility in order fulfillment (C2) ** • Visibility (C5) * • Recovery (C8) * • Dispersion (C9) * • Collaboration (C10) * • Market position (C12) * • Financial strength (C14) *

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Table 4.2: Vulnerability Factor Linkages

A similar process was performed at the sub-factor level. Here, the selection of disruptions to study during the case studies was a significant source of bias as some sub-factors were covered in depth while other potentially significant areas were not addressed. Cases were selected by each firm's sponsor, not to force an all-encompassing representation of the Supply Chain Resilience Framework but as significant events that could be clearly defined for the participants and had a major impact on operations. The intent was to learn what anticipation, reaction and adaptation efforts would be of most value to the firm, thus exemplary examples for theory development in qualitative research (Eisenhardt and Graebner 2007). Sub-factor linkages by methodology are: 1) 590 theoretical linkages (20.8 percent of total 2,840 possible links), 2) 414 correlated links (14.6 percent of possible links at $\alpha = 0.10$) and 3) 232 case study linkages (8.2 percent of possible links). Results of the sub-factor-level triangulation are summarized in Table 4.3 with detailed sub-factor linkages presented in Tables 4.4 through 4.10. Of the 40 vulnerability sub-factors, this mixed-methods process identified 311 unique linkages at the 2-way level, with 90 percent of the vulnerability sub-factors covered by at least one of the 71 capabilities. These exploratory results provide an excellent guide for firms who have completed the SCRAM™ assessment and are taking the next step toward improving their resilience.

One-way Comparisons	Two-way Comparisons	Three-way Comparisons	Number of Linkages*, **
1) A or B or C			1,021
	1) A and B		95
	2) A and C		232
	3) B and C		36
	Two-way links		311
	Two-way links not three-way links		275
		1) A and B and C	36

A = Theoretical Linkages, B = Survey Correlations, C = Focus Group Connections
* Maximum possible linkages = 40 vulnerabilities x 71 capabilities = 2,840.
** $\alpha = 0.10$ for correlations.

Table 4.3: Summary of Sub-factor-level Linkages by Methodology

Vulnerability Factor	Sub-factor	Linked Capability Factors
Turbulence (V1)	Unpredictability in customer demand (V1.1)	• Commonality (C1.1) * • Product modularity (C1.2) ** • Multiple pathways (C1.3) * • Supply contract flexibility (C1.4) * • Alternate suppliers (C1.5) * • Logistics multi-sourcing (C2.1) * • Postponement (C2.2) * • Demand pooling (C2.3) ** • Inventory management (C2.4) ** • Reserve capacity (C3.3) * • Labor productivity (C4.1) * • Asset utilization (C4.2) * • Information technology (C5.1) * • Asset visibility (C5.2) * • Information exchange (C5.3) * • Business intelligence (C5.4) * • Strategic gaming and simulation (C6.2) * • Seizing advantage (C6.3) * • Lead-time reduction (C6.5) * • Learning from experience (C6.6)* • Demand forecasting (C7.1) * • Risk identification and prioritization (C7.2) * • Recognition of early warning signals (C7.4) * • Contingency planning and exercising (C7.5) * • Recognition of opportunities (C7.6) * • Resource mobilization (C8.1) * • Consequence mitigation (C8.4) * • Dispersion of markets (C9.5) * • Collaborative forecasting (C10.1) * • Collaborative information sharing (C10.2) * • Postponement of orders (C10.3) ** • Product life cycle management (C10.4) ** • Risk sharing (C10.5) * • Creative problem solving (C11.1) * • Accountability (C11.2) * • Benchmarking (C11.5) * • Market share (C12.3) * • Customer relationships (C12.5) * • Customer communications (C12.6) * • Price margin (C14.4) *

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Continued

Table 4.4: Turbulence Linkages

Table 4.4 continued

Vulnerability Factor	Sub-factor	Linked Capability Factors
Turbulence (V1)	Fluctuations in currencies and prices (V1.2)	• Consequence mitigation (C8.4) * • Price margin (C14.4) *
	Exposure to geopolitical disruptions (V1.3)	• Alternate distribution channels (C2.5)* • Business intelligence (C5.4) * • Seizing advantage (C6.3) * • Learning from experience (C6.6)* • Recognition of early warning signals (C7.4) * • Communications strategy (C8.2) * • Consequence mitigation (C8.4) ** • Risk sharing (C10.5) ** • Substitute leadership (C11.4) * • Financial reserves (C14.1) * • Portfolio diversification (C14.2) *
	Exposure to natural disasters (V1.4)	• Demand pooling (C2.3) * • Back-up utilities (C3.1) * • Asset visibility (C5.2) * • Recognition of early warning signals (C7.4) * • Recognition of opportunities (C7.6) * • Resource mobilization (C8.1) * • Crises management (C8.3) * • Caring for employees (C11.6) *
	Unforeseen technology failures (V1.5)	• Lead-time reduction (C6.5) * • Demand forecasting (C7.1) * • Consequence mitigation (C8.4) *
	Pandemic (V1.6)	• Empowerment (C9.4) * • Dispersion of markets (C9.5) *

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Vulnerability Factor	Sub-factor	Linked Capability Factors
Deliberate threats (V2)	Terrorism and sabotage (V2.1)	• Alternate sources (C1.5) * • Redundant assets (C3.2) * • Recognition of early warning signals (C7.4) *
	Piracy and theft (V2.2)	• Asset visibility (C5.2) * • Lead-time reduction (C6.5) * • Learning from experience (C6.6)* • Consequence mitigation (C8.4) * • Decentralization of resources (C9.1) * • Layered defenses (C13.1) * • Access restriction (C13.2) * • Insurance coverage (C14.3) *
	Union activities (V2.3)	• Reserve capacity (C3.3) * • Re-routing requirements (C6.1) * • Learning from experience (C6.6) * • Contingency planning (C7.5) * • Communications strategy (C8.2) * • Crisis management (C8.3) ** • Consequence mitigation (C8.4) * • Risk sharing (C10.5) * • Market share (C12.3) *
	Special interest groups (V2.4)	• Lead-time reduction (C6.5) *
	Industrial espionage (V2.5)	• Back-up utilities (C3.1) * • Redundant assets (C3.2) * • Risk identification and prioritization (C7.2) * • Monitoring normal deviations (C7.3) * • Collaborative information sharing (C10.2) * • Brand equity (C12.1) * • Layered defenses (C13.1) * • Access restriction (C13.2) * • Employee involvement in security (C13.3) * • Collaboration with governments (C13.4) * • Cyber-security (C13.5) * • Personnel security (C13.6) * • Portfolio diversification (C14.2) *
	Product liability (V2.6)	• *No specific linkages*

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Table 4.5: Deliberate Threats Linkages

Vulnerability Factor	Sub-factor	Linked Capability Factors
External pressures (V3)	Competitive innovation (V3.1)	• Lead-time reduction (C6.5) * • Learning from experience (C6.6)*
	Government regulations (V3.2)	• Business intelligence (C5.4) * • Recognition of early warning signals (C7.4) *
	Price pressures (V3.3)	• Customer loyalty (C12.2) * • Product differentiation (C12.4) * • Customer communications (C12.6) *
	Corporate responsibility (V3.4)	• Business intelligence (C5.4) * • Recognition of early warning signals (C7.4) * • Customer relationships (C12.5) *
	Social/cultural changes (V3.5)	• Recognition of early warning signals (C7.4) * • Customer relationships (C12.5) * • Customer communications (C12.6) *
	Environmental issues (V3.6)	• *No specific linkages*

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Table 4.6: External Pressures Linkages

Vulnerability Factor	Sub-factor	Linked Capability Factors
Resource limits (V4)	Supplier capacity (V4.1)	• Commonality (C1.1) * • Alternate sources (C1.5) ** • Recognition of early warning signals (C7.4)** • Contingency planning (C7.5) * • Resource mobilization (C8.1) ** • Risk sharing (C10.5) * • Customer communications (C12.6) **
	Production capacity (V4.2)	• Alternate sources (C1.5) ** • Logistics multi-sourcing (C2.1) * • Inventory management (C2.4) * • Alternate distribution channels (C2.5)* • Redundant assets (C3.2) ** • Reserve capacity (C3.3) ** • Preventative maintenance (C4.4) * • Failure prevention (C4.5) * • Rerouting of requirements (C6.1) * • Seizing advantage (C6.3) ** • Learning from experience (C6.6)* • Recognition of early warning signals (C7.4) * • Contingency planning (C7.5) * • Crises management (C8.3) * • Consequence mitigation (C8.4) * • Market share (C12.3) ** • Customer relationships (C12.5) * • Customer communications (C12.6) * • Price margin (C14.4) *

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Continued

Table 4.7: Resource Limits Linkages

Table 4.7 continued

Vulnerability Factor	Sub-factor	Linked Capability Factors
Resource limits (V4)	Distribution capacity (V4.3)	• Supply contract flexibility (C1.4) * • Logistics multi-sourcing (C2.1) ** • Demand pooling (C2.3) * • Alternate distribution channels (C2.5)* • Reallocation of production (C2.6) * • Redundant assets (C3.2) * • Reserve capacity (C3.3) * • Information technology (C5.1) * • Information exchange (C5.3) * • Rerouting of requirements (C6.1) * • Lead-time reduction (C6.5) * • Learning from experience (C6.6)* • Recognition of early warning signals (C7.4) * • Contingency planning (C7.5) * • Resource mobilization (C8.1) * • Consequence mitigation (C8.4) * • Distributed capacity (C9.2) * • Dispersion of markets (C9.5) * • Collaborative forecasting (C10.1) * • Collaborative information sharing (C10.2) * • Postponement of orders (C10.3) * • Risk sharing (C10.5) * • Customer communications (C12.6) * • Access restriction (C13.2) * • Financial reserves (C14.1) * • Price margin (C14.4) *
	Raw material availability (V4.4)	• Alternate sources (C1.5) * • Contingency planning (C7.5) * • Insurance coverage (C14.3) *
	Utilities availability (V4.5)	• *No specific linkages*
	Human resources (V4.6)	• Reserve capacity (C3.3) * • Labor productivity (C4.1) * • Communications strategy (C8.2) * • Crises management (C8.3) * • Accountability (C11.2) * • Diversity of skills (C11.3) * • Substitute leadership (C11.4) ** • Customer relationships (C12.5) *

Vulnerability Factor	Sub-factor	Linked Capability Factors
Sensitivity (V5)	Utilization of restricted materials (V5.1)	• Alternate sources (C1.5) * • Consequence mitigation (C8.4) **
	Importance of product purity (V5.2)	• Commonality (C1.1) * • Reallocation of production (C2.6) * • Redundant assets (C3.2) * • Information exchange (C5.3) * • Lead-time reduction (C6.5) * • Learning from experience (C6.6)* • Risk identification and prioritization (C7.2) * • Crises management (C8.3) * • Consequence mitigation (C8.4) * • Customer relationships (C12.5) * • Customer communications (C12.6) *
	Fragility (V5.3)	• Learning from experience (C6.6)* • Recognition of early warning signals (C7.4)** • Communications strategy (C8.2) * • Customer relationships (C12.5) ** • Customer communications (C12.6) **
	Complexity of process operations (V5.4)	• Reserve capacity (C3.3) * • Failure prevention (C4.5) * • Alternate technology (C6.4) * • Learning from experience (C6.6)* • Recognition of early warning signals (C7.4) * • Communications strategy (C8.2) * • Consequence mitigation (C8.4) *
	Reliability of equipment (V5.5)	• Commonality (C1.1) * • Alternate distribution channels (C2.5)* • Redundant assets (C3.2) * • Asset utilization (C4.2) * • Failure prevention (C4.5) * • Information exchange (C5.3) * • Learning from experience (C6.6)* • Resource mobilization (C8.1) * • Crises management (C8.3) * • Consequence mitigation (C8.4) *
	Potential safety hazards (V5.6)	• *No specific linkages*

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Continued

Table 4.8: Sensitivity Linkages

Table 4.8 continued

Vulnerability Factor	Sub-factor	Linked Capability Factors
Sensitivity (V5)	Visibility of disruption to stakeholders (V5.7)	• Seizing advantage (C6.3) * • Consequence mitigation (C8.4) * • Postponement of orders (C10.3) *
	Symbolic profile of brand (V5.8)	• Brand equity (C12.1) *
	Concentration of capacity (V5.9)	• Decentralization of key resources (C9.1) * • Distributed suppliers (C9.2) *

Vulnerability Factor	Sub-factor	Linked Capability Factors
Connectivity (V6)	Scale and extent of supply network (V6.1)	• Commonality (C1.1) * • Supply contract flexibility (C1.4) * • Alternate sources (C1.5) * • Demand pooling (C2.3) * • Alternate distribution channels (C2.5)* • Reallocation of production (C2.6) * • Reserve capacity (C3.3) * • Asset visibility (C5.2) * • Information exchange (C5.3) * • Alternate technology (C6.4) * • Lead-time reduction (C6.5) * • Learning from experience (C6.6)* • Distributed suppliers (C9.1) ** • Dispersion of markets (C9.5) * • Collaborative information sharing (C10.2) * • Risk sharing (C10.5) ** • Customer loyalty (C12.2) * • Market share (C12.3) * • Customer relationships (C12.5) * • Price margin (C14.4) *
	Import/export channels (V6.2)	• Alternate sources (C1.5) * • Lead-time reduction (C6.5) ** • Demand forecasting (C7.1) * • Distributed suppliers (C9.1) * • Distributed assets (C9.2) * • Dispersion of markets (C9.5) * • Market share (C12.3) * • Customer relationships (C12.5) * • Collaboration with governments (C13.4) * • Price margin (C14.4) *
	Reliance upon specialty sources (V6.3)	• Alternate sources (C1.5) * • Business intelligence (C5.4) * • Alternate technology (C6.4) * • Product differentiation (C12.4) * • Price margin (C14.4) *

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Continued

Table 4.9: Connectivity Linkages

Table 4.9 continued

Vulnerability Factor	Sub-factor	Linked Capability Factors
Connectivity (V6)	Reliance upon information flow (V6.4)	• Back-up utilities (C3.1) * • Information technology (C5.1) * • Asset visibility (C5.2) ** • Information exchange (C5.3) ** • Rerouting of requirements (C6.1) * • Learning from experience (C6.6)* • Recognition of early warning signals (C7.4)** • Resource mobilization (C8.1) * • Communications strategy (C8.2) * • Consequence mitigation (C8.4) * • Collaborative forecasting (C10.1) * • Collaborative information sharing (C10.2) * • Product life cycle management (C10.4) * • Accountability (C11.2) * • Customer communications (C12.6) ** • Cyber-security (C13.5) *
	Degree of outsourcing (V6.5)	• Product modularity (C1.2) * • Inventory management (C2.4) * • Information exchange (C5.3) * • Dispersion of markets (C9.5) *

Vulnerability Factor	Sub-factor	Linked Capability Factors
Supplier/ Customer disruptions (V7)	Supplier disruptions (V7.1)	• Commonality (C1.1) * • Supply contract flexibility (C1.4) ** • Alternate distribution channels (C2.5)** • Asset visibility (C5.2) * • Information exchange (C5.3) ** • Lead-time reduction (C6.5) * • Learning from experience (C6.6)* • Risk identification and prioritization (C7.2) * • Recognition of early warning signals (C7.4) * • Contingency planning and exercising (C7.5) * • Communications strategy (C8.2) * • Crises management (C8.3) * • Consequence mitigation (C8.4) * • Dispersion of markets (C9.5) * • Postponement of orders (C10.3) * • Risk sharing (C10.5) * • Creative problem solving (C11.1) * • Accountability (C11.2) * • Benchmarking (C11.5) * • Customer loyalty (C12.2) ** • Customer communications (C12.6) ** • Price margin (C14.4) **
	Customer disruptions (V7.2)	• Commonality (C1.1) * • Product modularity (C1.2) * • Multiple pathways (C1.3) * • Supply contract flexibility (C1.4) * • Alternate suppliers (C1.5) * • Logistics multi-sourcing (C2.1) * • Production postponement (C2.2) * • Demand pooling (C2.3) * • Asset visibility (C5.2) * • Recognition of early warning signals (C7.4) * • Recognition of opportunities (C7.6) * • Resource mobilization (C8.1) * • Collaborative forecasting (C10.1) * • Postponement of orders (C10.3) * • Risk sharing (C10.5) * • Price margin (C14.4) *

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Table 4.10: Supplier/Customer Disruption Linkages

Limitations and Recommendations

This exploratory study is the beginning of a process. Resilience tenets must be expanded to a broader base in large-sample evaluations, as well as refined with industry-specific modifications and re-validated. Another aspect that must remain for future study is the evaluation of balanced resilience in terms of long-term profitability, as compared to resilience in the operational view of this study. To accomplish this, longitudinal studies or approximations with network simulations are needed to compare the investments required to improve balanced resilience against the changes that occur over time. This is critical because when operations are going smoothly no one wants to invest in resilience, but during or after a major disruption everyone asks why they didn't.

Additionally, this study employed subjective inputs only, which can be improved by supplementing objective data as appropriate; however, as stated previously, subjective responses are appropriate when dealing with complex and interrelated issues as in the case of supply chain resilience. Also, future research can compare individual linkages to directly related performance metrics in further validation of the concept of resilience. Enhancements in the assessment process can also be achieved through the integration of inputs from suppliers, customers and other stakeholders, either participating directly in a consolidated assessment or in fielding separate assessments at multiple tiers within the supply chain. Next, additional validation and investigation of vulnerability-capability linkages should be conducted and is recommended for future studies to focus on a single area of vulnerability, first in a general sense and then in industry-specific terms. Analysis of focus group responses by disruption type may provide additional insight into the best

method of applying resilience and the most appropriate functional areas to instill various resilience attributes. Future work must also examine the process of aligning corporate strategy with the risk tolerance of the stakeholders and integrating resilience concepts into existing supply chain processes. And finally, a design-for-resilience process is necessary to evaluate potential alternative network designs through modification of a supply chain's vulnerabilities in comparison to the return-on-investment of managerial changes directly affecting capabilities, tying financial measures and potential resilience states.

CONCLUSIONS

The current problem, according to Sheffi (2008), is how to convince senior management to invest in resilience programs when things are going well? As we can now measure resilience and recommend directions for action, this research provides an initial foundation. This foundation is based on the inference of a positive relationship between increasing resilience and improved performance of supply chain operations. Although further validation is required, managers should be encouraged to make the minimal investment required to determine their current state of resilience and compare their strategy with the resilience fitness space. The linkages presented in this chapter provide direction for supply chain leaders, combined with the prioritizations detailed in their SCRAM™ report, to take necessary actions to improve critical capabilities, maintain high priority strengths and reduce unnecessary expenses. These actions, closely monitored and managed over time, will lead a firm toward a state of more balanced

resilience. Applying the concepts throughout the tiers of a supply chain will aligned resilience to reduce the overall risk of disruptions and create the capacity to survive, adapt and grow. The Supply Chain Resilience Framework provides the foundation, and the Supply Chain Resilience Assessment and Management (SCRAM^{TM}) tool provides the means to implement a resilience improvement process necessary to ensuring supply chain resilience.

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CHAPTER 5

CONCLUSION

Managing change is essential. In the corporate environment not being prepared for change and not designing and managing a supply chain that can react and adapt quickly can be very costly. "After adjusting for industry and economy effects, the average effect of disruptions in the year leading to the disruption [announcement] is a 107 percent drop in operating income, 7 percent lower sales growth and 11 percent growth in cost" (Hendricks and Singhal 2005). This exploratory study used supply chain performance measures to provide an initial assessment to infer that increased resilience improved operating performance for the firms within this study. Results show a potential for a 26 percent improvement in performance volatility for a single percentage point increase in resilience score as assessed by the Supply Chain Resilience Assessment and Management (SCRAM™) tool for these seven companies (see Figure 4.2 at sample mean resilience). Larger studies will be needed to confirm these results, but the evidence from business literature, industry leaders and academics also confirms the necessity for resilience (FM Global 2007; Council on Competitiveness 2007; Sheffi 2008).

This study advances the understanding of supply chain resilience through the development of the Supply Chain Resilience Framework, the SCRAM™ tool and identification of potential vulnerability-capability linkages to implement a process

improvement initiative. This process, as developed throughout Chapters 2 through 4, is depicted in Figure 5.1. Current thought on resilience is lacking because it is based on the successful, but limiting, foundations of risk management (Franck 2007) and simplistic definitions of resilience. As discussed in Chapter 2, traditional risk management is a successful tool when events can be clearly identified, probability of occurrence and potential severity can be accurately quantified and future events occur in similar fashion to the past. In an increasingly complex society, these assumptions are becoming less and less applicable. However, the concept of resilience for supply chain operations has proven potential to improve overall operational performance, both in times of dramatic change and times of relative stability (Flynn 2008).

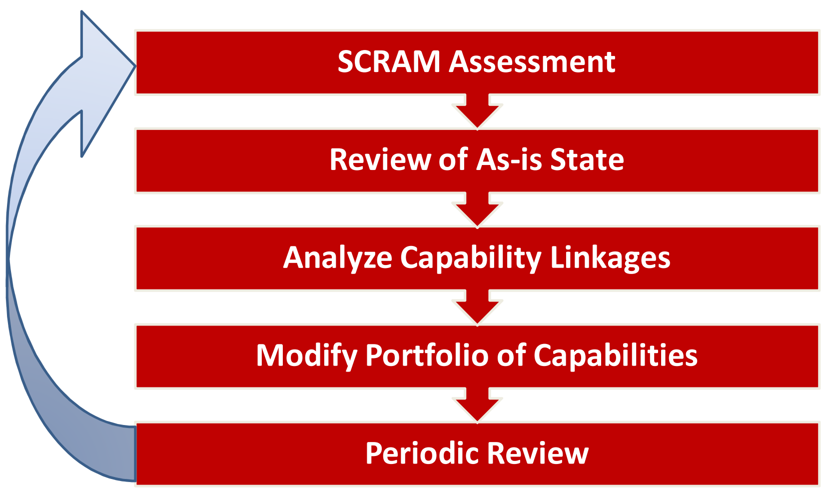

Figure 5.1: Resilience Improvement Process

Chapter 2 contributed to a growing field of supply chain resilience literature by combining limited conceptual viewpoints into an enterprise-wide view that addresses each phase of the disruption cycle – preparation, initial response, recovery and learning (Sheffi and Rice 2005). Resilience, the ability to survive, adapt and grow in the face of turbulent change (Fiksel 2006), can now be assessed as the balance between seven inherent supply chain vulnerabilities and 14 controllable capabilities, not simply abstract concepts such as robustness or agility. This project further refined the basic constructs into sub-factors that can be directly measured and acted upon, making the 111 items of the Supply Chain Resilience Framework a useful tool for supply chain managers.

To implement the framework, Chapter 3 presented a secure, on-line assessment tool designed to pool the expertise of a multi-function team to subjectively assess their supply chain's current level of vulnerabilities and capabilities. Through a process of evaluating the current level of resilience with leadership's desired state on the resilience fitness space (see Figure 2.4), management can prioritize investments based on the comparison of each vulnerability rating against the strengths and weakness of capability factors. Validation of the SCRAM™ tool was presented using data from five global manufacturing firms that participated in 14 case studies. Through this diverse sample, the SCRAM™ tool shows promise for application regardless of the industry. Further testing and industry-specific enhancements will serve to increase the validity and reliability of the tool.

However, the assessment tool only provides insight into the current state of supply chain resilience. Chapter 4 presented a mixed-methods triangulation that was

developed to translate the SCRAM™ tool into the next step of a resilience improvement process (Figure 5.1). By comparing theoretical connections between specific vulnerability and capability sub-factors with a similar matrix of assessment correlations, a more refined set of potential linkages was identified. Comparing this matrix with a third matrix of possible linkages that were uncovered through the validation focus groups, further increases the construct validity of the results through triangulation. Although none of the individual methods were without bias and limitations, the confluence of two methods and especially the triangulation of the three methods provides a high level of confidence in the resulting linkage matrix, as presented in Tables 4.4 through 4.10. Through a process of breaking-down higher level constructs into controllable variables that were developed during presentation and discussion of the seven SCRAM™ studies (see Appendices A-G), a firm can now compare their current vulnerability priorities with a list of potential capability sub-factors in order to improve their state of balanced resilience by increasing or decreasing capabilities. Thus, assessment and periodic re-assessment forms the basis of managing the dynamic portfolio of capabilities that are best matched to the pattern of inherent vulnerabilities to ensure supply chain resilience in a world of turbulent change.

Future research opportunities abound in this area as validated by practitioners and academics alike. Following independent, large-scale confirmation of the framework and assessment tool, more detailed investigation of vulnerabilities can supplement the potential links presented herein. Adaptation of the assessment tool with the consolidation of objective measures of vulnerabilities, capabilities and performance will further add to

the fidelity of the assessment process. And finally, as mentioned previously, the addition of industry and firm-specific measurements will provide additional insight.

Supply chain managers are striving to create resilient supply chains. Just like legendary leaders throughout history, Estep (2005) concludes with a metaphor, originally popularized by President Kennedy (1959), which focuses the concept of resilience on avoiding the negative ramifications of disruptions with the positive prospect of seizing advantage from change:

> Peak performers use the Chinese symbol for *crisis* as the sign of resiliency. This symbol is made up two parts: the character for "*danger*" and the character for "*opportunity*," suggesting that opportunities often hide in crises. *(emphasis added)*

Although others highlight that the second character of the word for crisis (wei-ji) is more accurately translated as "an incipient moment" or "crucial point when something begins or changes" (Mair 2008), this meaning can still be appropriately applied as the *danger* of change is now, and the understanding of supply chain resilience can be the *crucial turning point*. Therefore, with the application of resilience management, supply chain leaders can now direct their supply chains toward peak performance.

危 机

(wei-ji)

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APPENDIX A

COMPANY A

Overview

Company A is a global retailer of major brands in the personal care, beauty products and apparel categories. Company A designs and tests its products, but outsources all production activities. Logistics services are centrally managed for all brands creating an integrated distribution network. Company A's products are available in over 2,900 specialty stores nationwide, with a limited selection of brands also utilizing catalog and internet retailing. Company A recorded sales of $10 billion in 2007 and employs more than 90,000 associates throughout the United States.

Note: Company A requested that their SCRAM™ assessment not be published herein.

APPENDIX B

COMPANY B

Overview

Company B is a regional division of a multinational consumer electronics corporation headquartered in the United States. Sales for this division are concentrated in 2 major countries with many smaller markets spread through a large geographic region. Some logistics services are centralized with other product divisions serving the same region, including warehousing and distribution. Revenue for this division is in the range of $2.0 billion annually.

Assessment Results: Company B

Supply Chain Resilience Assessment
SCRAM™ 1.1

July 2007

prepared by:

Mr. Tim Pettit,
Dr. Joseph Fiksel,
and
Dr. Keely Croxton

Center for Resilience and Fisher College of Business
The Ohio State University

EXECUTIVE SUMMARY

This self-assessment was completed at Company B, by a team of 22 individuals, July 6 - 17, 2007.

In a world of turbulent change, resilience is a key competency — since even the most carefully designed supply chain is susceptible to unforeseen factors. Businesses must be prepared to cope with a continuous stream of challenges, ranging from human errors to technological failures to natural disasters.

The Center for Resilience at The Ohio State University (OSU) has developed a new supply chain resilience framework to assist businesses deal with change: ***resilience*** is "the ability of an enterprise to survive, adapt and grow in the face of change and uncertainty." We created a tool for measuring resilience in a business enterprise – Supply Chain Resilience Assessment & Management (**SCRAM**™) – to assess supply chain resilience in terms of two major dimensions:

- **Vulnerabilities** – fundamental factors that make an enterprise susceptible to disruptions
- **Capabilities** – attributes that enable an enterprise to anticipate and overcome disruptions

We define the Zone of Balanced Resilience as a balance between vulnerabilities and capabilities, where firms will be the most profitable in the long term.

This report includes detailed results of the assessment and recommendations. Significant recommendations are as follows:

- Company B is currently operating slightly outside of the desired Zone of Balanced Resilience. Overall, the team reported that the firm is currently in a more conservative, risk adverse region, which may be eroding profitability.
- Company B's strongest capability is Security, which is a strategic asset, but may be overemphasized based on its relatively low vulnerability to Deliberate Threats.
- The Group's highest vulnerability is Connectivity which is a concern due to reported low capabilities in Collaboration and Visibility, which should be reviewed for improvement.
- The second ranked vulnerability is External Pressures, such as price pressures and competitive innovations, which can be significantly influenced by attributes such as Flexibility in Sourcing and Flexibility in Order Fulfillment, both currently weak. In a market with short life-cycles and high margins on innovative products, focus on manufacturing flexibility and supply contract flexibility could provide additional competitive advantages against these external pressures.
- Supply chain vulnerabilities were rated significantly lower than expected for a global supply chain such as Company B, while the importance of supplier and

customer reliability was rated predictably high. Further analysis by Company B into supplier and customer vulnerabilities is recommended.

Company B has taken an important first-step in exploring resilience. The Center for Resilience at The Ohio State University is dedicated to collaborating with Company B in future research to determine methods of integrating the resilience framework with existing risk management programs at Company B and throughout the entire Company B enterprise.

Assessment Results

Company B

Goals and Scope

Through in-depth discussions with the project directors at Company B, the goal of the project was first defined to extend the existing Risk Management program to incorporate the concept of resilience. Therefore, the scope of the project is limited to this group's operations throughout [their operating region], which should be noted does not include corporate support such as product development and production. However, services received from others in the Company B enterprise were evaluated as members of the Company B extended supply chain.

Team Composition

The Company B Resilience Assessment Team was selected using a multi-level, cross-functional design. Membership from operations as well as mid- and senior-management is desired to provide coverage of both tactical and strategic issues. Additionally, including members from each functional specialty within the scope of the study ensures that the team comprises detailed experiences in each of the categories included in the broad framework of supply chain resilience. Review of the titles and self-reported functional roles confirm that the team composition adequately reflected the multi-level and cross-functional design. A total of 22 participants comprised the Resilience Assessment Team, with their functional roles depicted in Figure B.1.

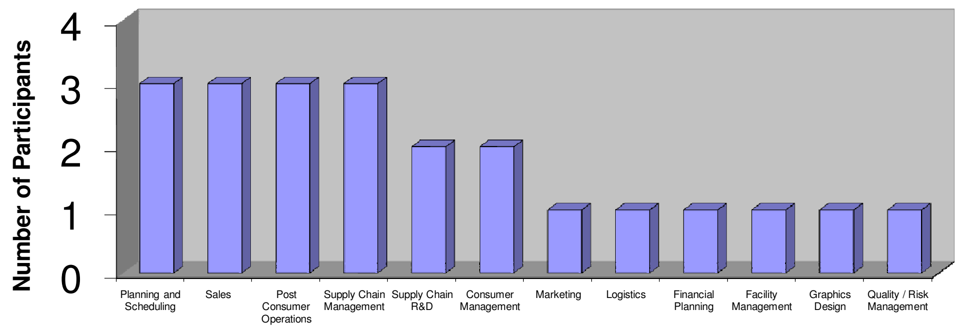

Figure B.1: Team Composition

Resilience Measurement

Each team member completed the secure, on-line assessment during the period of July 6th to 17th, 2007. The average amount of time to complete the survey was 30.1 minutes. During the assessment, team members responded to questions on a Likert Scale of 1 to 5, representing responses from "Strongly Disagree" to "Strongly Agree". Responses were coded anonymously and reviewed for data accuracy. Respondents were allowed to select "Don't Know" or leave questions blank to prevent inexperienced responses from biasing the results. A minor number of these responses were recorded and in general they matched well against the respondent's job title and functional area.

Analysis of the data began at the strategic level. Responses for each item were averaged to form Factor Scores for each of the seven Vulnerability factors and 14 Capability factors. An overall measure of resilience was then obtained by comparing the balance between the vulnerability and capability grand averages. Overall, Company B's

resilience assessment is in Zone 2, varying off the Zone of Balanced Resilience with a slight imbalance toward excessive capabilities (score of 3.8) as compared to the current vulnerabilities (score of 3.1). This assessment is graphically depicted in Figure B.2, with the composite score shown in Zone 2, fairly evenly clustered around the individual scores shown for reference.

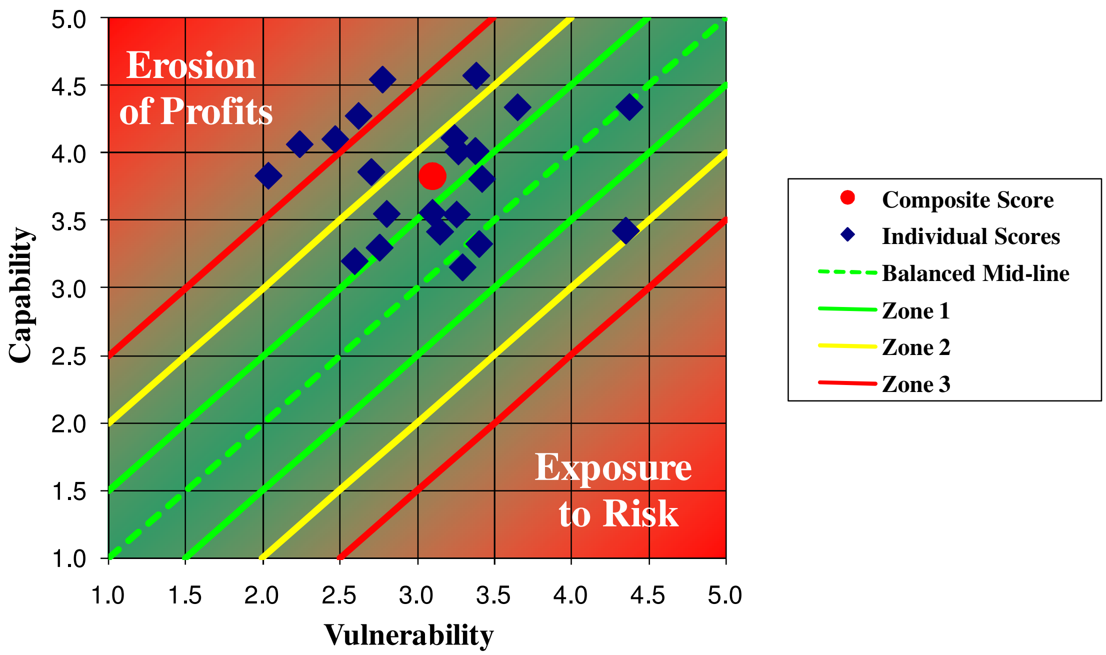

Figure B.2: Strategic Assessment Results

Only one individual reported a contrary response (scoring toward a moderate exposure to risk). This team member was from the Planning and Scheduling group, representing Consumer Planning. His/her responses appropriately reflected the requirements of the functional role of predicting and planning for consumer demand

which can be highly volatile. These scores were low in Anticipation, Visibility and Capacity, while high in Price Pressures and Competitive Innovations – all representative of demand issues. The analysis continues with review of vulnerability then capability findings, highlighting tactical issues as appropriate.

Vulnerability Results

The SCRAM™ assessment provided a clear distinction between high and low vulnerabilities. Overall, the responses are indicative of a global supply chain in a highly competitive, short product life cycle market. A summary of the scores and rankings are shown in Table B.1 and Figure B.3. Connectivity and External Pressures are the top issues facing Company B. The team identified the overall most vulnerable item as their dependence on consistent and accurate information flow, an item of Connectivity. The scale of the distribution network and number of supply chain members are also top Connectivity issues, with price pressures and competitive innovations as the top External Pressure issues. The importance of the symbolic "Company B" brand is also of critical importance to the firm, the top Sensitivity issue identified by the team. Finally, Resource Limits appears as a moderate vulnerability and Turbulence, Supply Chain Vulnerabilities and Deliberate Threats are minor issues. It should be noted that the responses were relatively more consistent for the top rankings and bottom ranking, which represents a strong consensus on the most important issues. Sub-factor rankings are presented in Table B.3, listed at the end of this report.

Ranking	Vulnerability	Average Score	Standard Deviation
1	Connectivity	4.15	0.65
2	External Pressures	3.78	0.78
3	Sensitivity	3.19	0.77
4	Resource Limits	2.92	0.86
5	Turbulence	2.66	0.75
6	Supply chain vulnerabilities	2.52	1.01
7	Deliberate Threats	2.51	0.86

Table B.1: Vulnerability Rankings

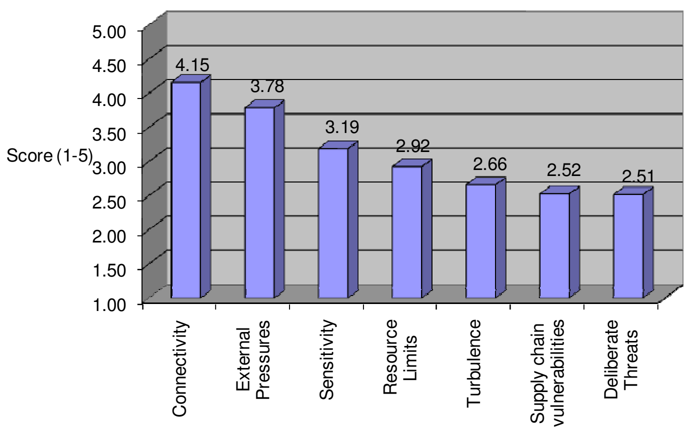

Figure B.3: Vulnerability Scores

Following the assessment of each factor, each team member was asked to report their perception of the relative importance of each of the measures. These questions were reserved for the end of the assessment to ensure that respondents were exposed to each of the vulnerability and capability factors in order to better determine their relative priorities. Results of the relative importance of vulnerabilities are shown in Figure B.4.

Two vulnerability factors stand out as factors regularly impacting operations: Connectivity and Supply Chain Vulnerabilities. The Group should concentrate on maintaining existing capabilities and improving new capabilities to combat Connectivity issues. Such areas would include ensuring reliable information flow, improving channel coordination and reducing the number of network nodes. Second, supply chain vulnerabilities are also of critical importance to Company B. This is reflected in two dimensions: supplier reliability and customer disruptions. Supplier reliability is critical to ensure a consistent flow of inbound product and information in order to keep Company B processes operating smoothly. A more detailed assessment of the intricacies of supplier interaction is recommended. As for customer disruptions, this area is difficult to address for retail channels as customers are end-consumers. Disruptions to customer demand would include areas such as access to retail outlets during or following natural disasters that disrupt traffic flows or usage patterns. If customer access is an issue, further studies would be recommended.

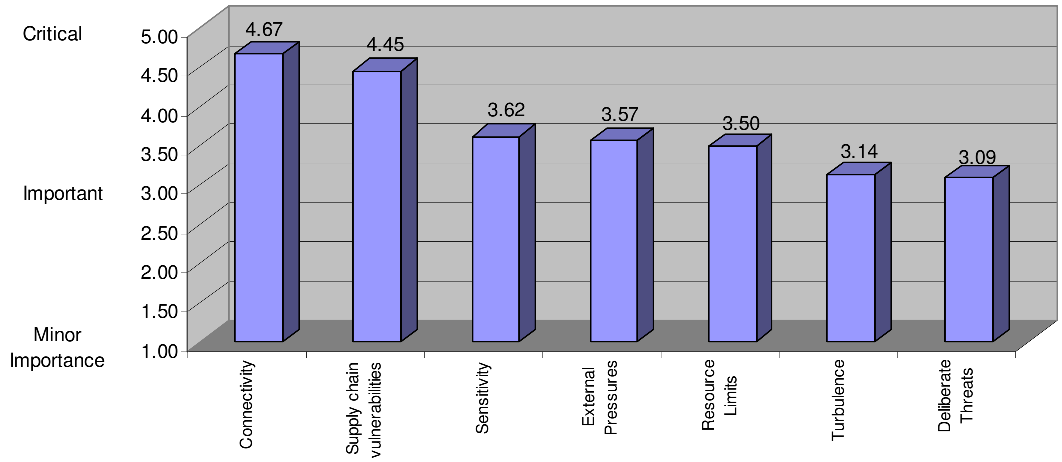

Figure B.4: Importance of Vulnerabilities

As vulnerabilities represent the fundamental factors that make an enterprise susceptible to disruptions, these factors are considered inherent in the enterprise's operating environment and therefore can not be affected in the short term, and in the long term strategic decisions altering the environment would radically change the supply chain and invalidate the assessment results. Therefore, tactical recommendations will be targeted to the capability scores which are the methods that an enterprise can anticipate and overcome disruptions.

Capability Results

In order to combat vulnerabilities, research has shown that a supply chain must have the capability to overcome its vulnerabilities for long-term survival. These supply chain capabilities create the ability to anticipate and prevent a disruption, mitigate the effects of a disruption or adapt with new, more profitable processes, products or services. Table B.2 and Figure B.5 summarize the capability scores for Company B's self-assessment. Detailed sub-factor rankings are presented in Table B.4, listed at the end of this report.

Company B's Resilience Team reported their strongest capability as Security. Scores were high in all areas of Security: personnel security, IT protection, access restrictions, employee involvement and layered defenses. Matching this capability to associated vulnerabilities, Company B's strength in IT security should continue to be a top priority to maintain protection of supply chain data (#1 of 40 vulnerability items). However, security programs designed to deter theft, industrial espionage and sabotage may be overemphasized at Company B as shown by the relatively low scoring for these Deliberate Threats.

Ranking	Capability	Average Score	Standard Deviation
1	Security	4.41	0.47
2	Market Position	4.37	0.47
3	Organization	4.23	0.68
4	Dispersion	4.12	0.52
5	Recovery	4.05	0.39
6	Efficiency	3.90	0.54
7	Financial strength	3.87	0.53
8	Anticipation	3.64	0.76
9	Adaptability	3.61	0.62
10	Capacity	3.58	0.71
11	Collaboration	3.57	0.81
12	Visibility	3.52	1.16
13	Flexibility in Order Fulfillment	3.52	0.80
14	Flexibility in Sourcing	3.29	0.70

Table B.2: Capability Rankings

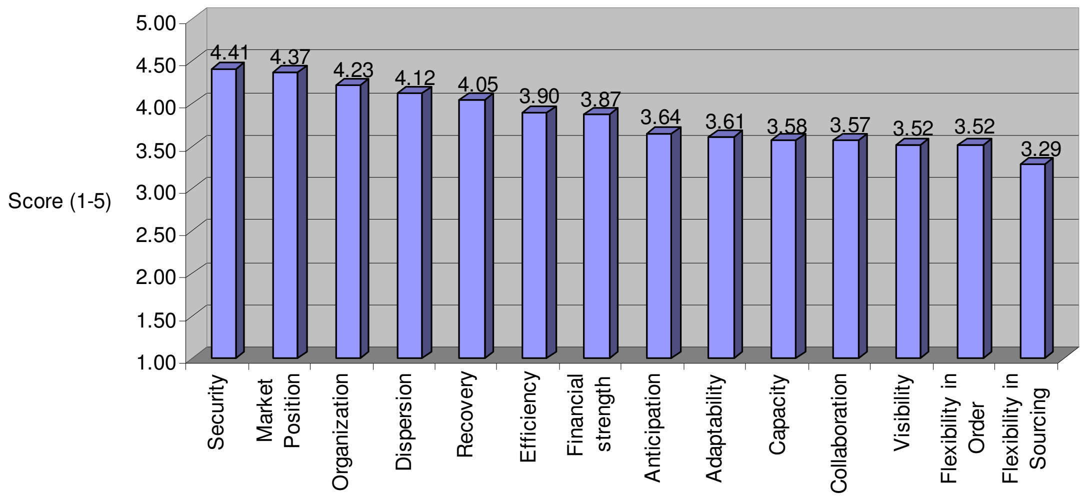

Figure B.5: Capability Scores

The Group's second ranked capability is Market Position. Company B is successful in developing a valuable brand image and controlling a strong market share. And although the team reported a high level of product differentiation, maintaining this strength should be a high priority to management based on the significant vulnerability to price pressures and competitive innovation. Company B's organizational structure and culture are assets to Company B; however, the Group should consider policies that address empowerment of dispersed leadership in the event that higher staff levels loose communication with operating units. Company B's market is dispersed geographically, but the team reported that key facilities and resources were too concentrated.

On the opposite extreme, Company B's lowest capability scores are in Flexibility in Sourcing, Flexibility in Order Fulfillment, Visibility and Collaboration. First, Flexibility in Sourcing should be a major area of concern in Company B's highly volatile

market with short product life cycles. The team scored the firm's ability to modify supplier contracts and utilize alternate suppliers as low. Improving both of these capabilities will allow for faster reaction to market changes. Although Company B has had successful product postponement programs, the team scores indicate that Company B should continue increased use of common parts in multiple products and improving component modularity in design, both allowing for smaller safety stocks and faster final assembly speeds. Delaying final production will benefit the capability of Flexibility in Sourcing.

Next, Flexibility in Order Fulfillment was rated second lowest. Company B should work with storage and distribution partners to ensure that sufficient capacity is available to meet peak demands and allow flexibility when one mode is disrupted for any reason. Capacity can be augmented with pre-arranged, as-needed contracts with alternate providers at little to no cost to Company B. In addition, improvements to Flexibility in Order Fulfillment can also be improved with further implementation of production postponement mentioned earlier, as well as with customer order delays. Moving toward an Assemble-to-Order production strategy would allow a segment of the market to accept back-orders instead of loosing sales when products are out-of-stock at retailers. Current inventory management and demand pooling programs are strengths in this area.

Visibility is of minor concern for Company B. Although there are strong IT solutions in-place, the team reported that not all data on assets, equipment and employees is accurate or timely. Additionally, more aggressive business intelligence and market research programs may successfully address vulnerabilities to competitive innovations.

Company B's collaborative information exchange processes were rated moderate, but can be improved to form stronger business relationships with suppliers and distribution agents to improve responsiveness to the #1 vulnerability of Connectivity.

Finally, the capability Collaboration is downgraded by a single item: customer unwillingness to postpone orders, which is typical of a retail environment. Company B should consider alternate retail channels and incentives that would contribute to increasing customer desires to delay purchases when inventory levels are low. Alternate channels could also include stronger sales to the corporate or governments markets. By relieving pressures on the production and distribution channels, a more efficient operation may be able to alleviate price pressures, which is the #2 vulnerability.

Analyzing the importance of the 14 Capability factors provides interesting insight into the relative priorities that should be placed on each area, Figure B.6. Company B is most focused on recovering when disruptions do occur; however, this should not be overemphasized to the expense of anticipation or prevention programs. In addition, many firms do not attempt to quantify the actual cost of recovery; Company B should ensure a customer segmentation program is in place and available data estimates each customer's long-term value in order to weigh each recovery effort. Procedures which include advanced calculation of customer value and provide categories of pre-authorized recovery services would be beneficial.

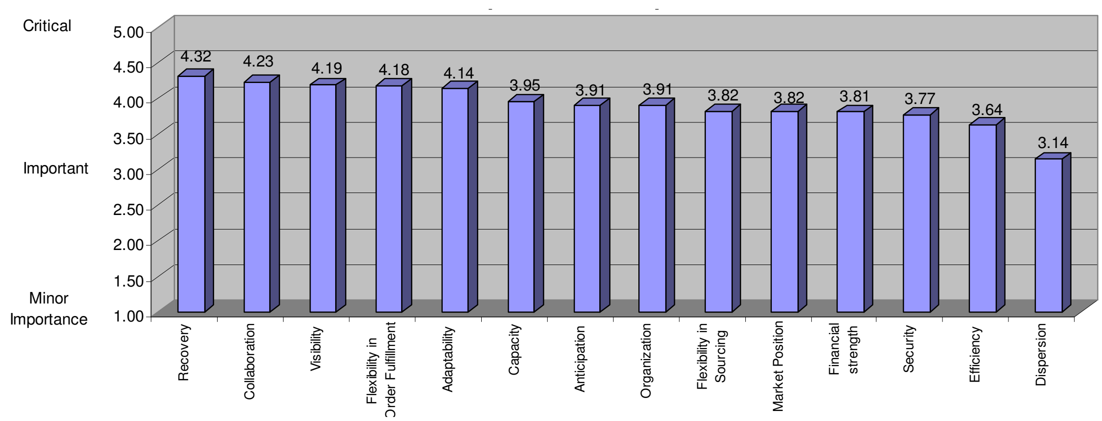

Figure B.6: Importance of Capabilities

Collaboration, Visibility and Flexibility in Order Fulfillment were also rated as critical. Comparing these findings with the capability rankings from Table B.2 (rankings of 11, 12 and 13 out of 14, respectively – all relatively low capabilities), it is clear that Company B needs to place significant emphasis in these three areas. Strong Adaptability is the final factor score with results over 4.0. Company B's corporate vision should emphasize change management and promote innovation as critical success factors.

On the other extreme, Dispersion was rated the least important, but still scoring greater than 3.0, or "Important". Management may be interested in further details into those localized disruptive factors to determine if in fact this capabilities is correct scored relatively low.

Resilience Recommendations

Company B is commended for compiling an excellent Resilience Assessment Team. The team's composition matched well with the scope and goals determined by the project leaders. Through the team's investment in approximately 11 man-hours, a significant number of important issues were uncovered. Specifically,

- Company B may be eroding profitability in some areas due to over-expenditure in capabilities.
- Security programs are successful but may be overemphasized.
- Connectivity is a concern due to reported low capabilities in Collaboration and Visibility.
- External Pressures such as price pressures and competitive innovations are the norm in Company B's markets, and capabilities such as Flexibility in Sourcing and Flexibility in Order Fulfillment should be improved.
- Additional research into supply chain vulnerabilities is recommended to uncover greater insight into supplier resilience throughout the upstream supply chain.

Follow-on studies at the Center for Resilience are currently being conducted to empirically test the ranges of the Zone of Balanced Resilience, as well as identifying significant linkages between vulnerabilities and capabilities that can improve overall supply chain performance. To accomplish this effort, historical performance data will be required for analysis. Company B is recommended to continue its collaboration with The Ohio State University to further integrate resilience measures into existing risk management programs.

Rank	Average	StDev	Item	Title
1	4.50	0.74	V6.4	Reliance upon information flow
2	4.45	0.83	V3.3	Price pressures
3	4.43	0.75	V5.8	Symbolic profile of brand
4	4.41	0.59	V6.2	Import/export channels
5	4.32	1.04	V3.1	Competitive innovation
6	4.15	0.88	V6.1	Scale and Extent of supply network
7	4.14	0.79	V5.2	Importance of product purity
8	3.95	0.92	V3.6	Environmental changes
9	3.85	1.23	V6.5	Degree of Outsourcing
10	3.70	0.80	V6.3	Reliance upon specialty sources
11	3.57	1.16	V4.1	Supplier capacity
12	3.55	1.06	V3.2	Government regulations
13	3.50	1.10	V3.4	Corporate responsibility
14	3.36	1.26	V4.2	Production capacity
15	3.33	1.06	V5.3	Fragility
16	3.27	1.20	V1.2	Fluctuations in currencies & prices
17	3.23	0.92	V1.1	Unpredictability in customer demand
18	3.18	1.30	V1.3	Exposure to geopolitical disruptions
19	3.14	1.24	V5.7	Visibility of disruption to stakeholders
20	3.10	1.26	V5.4	Complexity of process operations
21	3.10	1.37	V2.6	Product liability
22	3.06	1.11	V5.5	Reliability of equipment
23	3.05	1.13	V4.4	Raw material availability
24	3.05	1.13	V4.3	Distribution capacity
25	3.00	1.30	V2.2	Piracy & theft
26	3.00	1.34	V5.9	Concentration of capacity
27	2.91	1.41	V3.5	Social/Cultural changes
28	2.85	1.23	V2.5	Industrial espionage
29	2.67	1.20	V2.1	Terrorism & sabotage
30	2.60	0.94	V7.1	Supplier vulnerabilities
31	2.45	1.06	V7.2	Customer vulnerabilities
32	2.45	1.18	V1.4	Exposure to natural disasters
33	2.44	0.70	V5.1	Utilization of restricted materials
34	2.11	0.90	V4.5	Utilities availability
35	2.05	0.59	V4.6	Human resources
36	2.00	1.00	V1.5	Unforeseen technology failures
37	1.71	0.72	V1.6	Pandemic
38	1.71	0.78	V2.3	Union activities
39	1.62	0.67	V2.4	Special interest groups
40	1.45	0.76	V5.6	Potential safety hazards

Table B.3: Vulnerabilities by Score Rank

Rank	Average Score	StDev	Item	Title
1	4.77	0.43	C12.1	Brand equity
2	4.76	0.44	C9.5	Geographic dispersion of markets
3	4.68	0.57	C12.3	Market share
4	4.57	0.51	C13.6	Personnel security
5	4.53	0.51	C14.2	Portfolio diversification
6	4.52	0.51	C13.5	Cyber-security
7	4.48	0.51	C13.2	Access restriction
8	4.45	0.91	C11.6	Culture of caring for employees
9	4.41	0.67	C12.4	Product differentiation
10	4.41	0.80	C11.3	Diversity of skills & experience
11	4.40	0.63	C14.1	Financial reserves & liquidity
12	4.35	0.67	C13.3	Employee involvement in security
13	4.35	0.81	C6.5	Lead time reduction
14	4.32	0.78	C11.2	Accountability & empowerment
15	4.32	0.58	C4.5	Equipment reliability
16	4.31	0.48	C4.4	Failure prevention
17	4.30	0.80	C9.3	Distributed decision-making
18	4.27	0.70	C11.1	Creative problem solving culture
19	4.25	0.86	C13.4	Collaboration with governments
20	4.23	0.61	C12.2	Customer loyalty/retention
21	4.14	0.48	C8.1	Resource mobilization
22	4.14	0.77	C14.3	Insurance coverage
23	4.14	0.56	C8.4	Consequence mitigation
24	4.13	0.74	C13.1	Layered defenses
25	4.11	0.58	C2.3	Demand pooling
26	4.10	0.79	C7.5	Contingency planning/Preparedness
27	4.10	0.54	C8.2	Communications strategy
28	4.09	0.75	C6.6	Learning from experience
29	4.09	1.02	C12.5	Relationships
30	4.06	0.73	C4.3	Product/part variability reduction
31	4.05	0.76	C9.2	Distributed capacity & assets
32	4.05	1.07	C2.4	Inventory management
33	4.00	0.82	C7.3	Monitoring/Communicating deviations & “near misses”
34	4.00	0.94	C10.4	Product life cycle management
35	4.00	1.02	C11.5	Benchmarking/Feedback – Learning Organization
36	4.00	1.12	C3.1	Backup energy sources/communications
37	3.89	0.99	C12.6	Communications
38	3.87	1.13	C3.2	Redundancy (Assets, labor)
39	3.86	0.91	C10.1	Collaborative forecasting
40	3.86	1.11	C11.4	Substitute leadership capacity

Continued

Table B.4: Capabilities by Score Rank

Table B.4 continued

Rank	Average Score	StDev	Item	Title
41	3.84	0.60	C8.3	Crisis management
42	3.84	1.01	C9.4	Location-specific empowerment
43	3.81	0.66	C4.1	Labor productivity
44	3.77	1.27	C5.1	Information technology
45	3.76	1.00	C7.2	Risk identification & prioritization
46	3.68	0.95	C6.4	Alternative technology development
47	3.68	1.32	C5.3	Collaborative information exchange
48	3.67	0.97	C1.1	Common product platforms
49	3.65	0.93	C10.5	Risk sharing with partners
50	3.57	1.08	C7.1	Demand forecasting methods
51	3.52	1.12	C10.2	Transparency – information sharing
52	3.48	1.12	C2.5	Alternate distribution channels
53	3.43	0.81	C7.4	Recognition of early warning signals
54	3.43	1.02	C9.1	Decentralization of key resources
55	3.40	0.91	C1.2	Product/service modularity
56	3.38	1.15	C1.5	Alternate suppliers/Outsourcing options
57	3.36	1.36	C5.2	Products, Assets, People
58	3.35	0.93	C6.3	Seizing advantage from disruptions
59	3.33	0.84	C4.2	Asset utilization
60	3.29	1.20	C1.4	Supply contract flexibility
61	3.25	1.29	C5.4	Business intelligence gathering
62	3.19	0.98	C2.2	Delayed commitment/Production postponement
63	3.15	1.23	C7.6	Recognition of opportunities
64	3.12	1.05	C6.2	Strategic gaming & simulation
65	3.05	0.97	C14.4	Price margin
66	3.00	0.97	C3.3	Reserve capacity (Materials, assets, labor)
67	3.00	1.05	C6.1	Fast re-routing of requirements
68	3.00	1.11	C2.6	Delivery options
69	2.90	1.25	C2.1	Multi-sourcing (peak vs. base)
70	2.71	0.73	C1.3	Multiple pathways & skills
71	2.63	1.02	C10.3	Postponement of orders

Disruption Overviews

Contract Manufacturer Delays for New Product Launch
Company B, Disruption #1
(B1 – Supply-side)

The launch of a new product designed for commercial use experienced significant delays due to contract manufacturer issues. Although Company B uses manufacturing and logistics postponement to delay final product differentiation, the interface between Asian manufacturers and local final-assembly and packaging contributed to engineering errors which led to the delays.

Errors were identified during final pilot testing at the local assembly plant; however, a significant amount of product had already been manufactured and shipped from Asia. Additional rework, re-labeling and substitution of parts during final manufacture was required. Fortunately, the design used common components that allowed for substitution using on-hand stock previously purchased for a different end-item. Once changes were identified and communicated to the contract manufacturer, it took several more days to translate the engineering changes into their systems. In addition, although premium transportation was used to ship necessary items from Asia, an additional 4 days of delays were caused in the receiving and processing of items at the final assembly point.

Approximately 2 weeks after the initially planned launch, partial shipments were made to major customers as reworked product became available. In addition to lost sales of this product, it is estimated that losses in sales of services and consumables used for this product could exceed the value of the initial lost sales.

Warehouse Capacity Limitations to Meet End-of-Quarter Loads
Company B, Disruption #2
(B2 – Production)

End-of-Quarter loads create extreme challenges in throughput requirements. Loads are created due to compensation programs for sales personnel tied to meeting quarterly volume quotas combined with reward programs for customers exceeding quarterly volume targets. Customers achieving targets are extended price reductions for all purchases beyond the target. As a long-term corporate policy, customers have learned which products are most advantageous to "forward-buy" creating surges on a limited number of SKUs. It is believed that only a few customers actually pass on these cost savings to consumers in attempt to increase demand. Typically customers hold product for later sales; this is evidenced by significant reduced orders during the first and second months of the following quarter, despite relatively level consumer sales. For example, monthly sales during a representative quarter average 25 percent, 25 percent and 50 percent of the total quarterly volume, respectively. That represents a 100 percent increase in monthly volume, condensed into an actual 200 percent increase in throughput during the last 2 weeks of the quarter.

Compounding this problem, corporate forecasts and sales quotas are based on sales volume in terms of total value, not product-line or SKU-specific quantities. Procurement activities must convert quarterly forecasts into the item-specific buys to be filled throughout the quarter based economic and operational factors such as minimum quantities, economic order quantities, warehouse capacity, etc. The operational staff

reports that the last 2 weeks of each quarter are spent exclusively working the issue of allocating stock to meet the surge orders. In addition, customer credit issues arise due to the surge in orders, causing significant processing increases by finance staff, hampered by very frequent communications from sales representatives.

Current operational metrics are expected to continue to meet corporate performance standards even during these surge periods. Despite best efforts, delivery lead-times typically extend from 2-3 days to 4-7 days during the last 2 weeks of each quarter.

Additionally, warehouse management hires up to 50 percent additional temporary workers beginning 4 weeks before the End-of-Quarter for 2-weeks of training and preparation, followed by 2 weeks of beneficial production. Significant overtime is paid due to limited equipment availability and storage limitations. Saturday operations are typical during the last 2 weeks of each quarter, with some Sunday requirements that are upsetting to labor even at overtime rates. Additional material handling equipment is also rented regularly at higher rates than owned equipment costs. Corporate management reports that they do not see the direct effect of these labor surges due to outsourcing agreements with the warehouse operator, whose contract is negotiated on a standard per-piece basis. Sub-contractor indicates that surge costs are included in average piece-prices as bid in the 3-year contract (based on last 12 years of experience with Company B).

Instability in Government Regulations in Venezuela
Company B, Disruption #3
(B3 - Demand-side)

Background

Venezuela is known widely for its petroleum industry, accounting for roughly a third of GDP, around 80 percent of exports, and more than half of government revenues. During the 1960s Venezuelan governments stressed import-substitution policies, using protective tariffs to limit imports of manufactured goods and subsidies to promote the growth of domestic manufacturing. In the mid-1970s the government nationalized Venezuelan iron ore, oil and gas industries (Encyclopedia Britannica 2008). In 1998 Hugo Chávez was elected president and pushed for radical reforms including a new constitution that was adopted in December 1999. The National Assembly has twice voted to grant Chávez the ability rule by decree in several broadly defined areas, once in 2000 and again in 2007. Early in the 21st century the economy recovered enough that by 2007 the country had paid off its foreign debt. Determined to reduce U.S. economic influence in Venezuela and the rest of Latin America, Chavez in 2007 completed the takeover of the oil sector by seizing operational control of the last privately run oil operation in the country—the Orinoco basin oil projects—from foreign-owned companies (Encyclopedia Britannica 2008).

As a governmental control over importation, the Comisión de Administración de Divisas (CADAVI) has "the power to regulate and impose restrictions, called "Providences", on the requirements for purchasing foreign currency. They also have the power to issue or deny authorizations to purchase foreign currency and verify and control

the use of that foreign currency" (Stradafee 2008). The central government's Registry of Foreign Exchange Administration System (RUSAD) allocates authorization numbers for purchase of foreign currency; however, based on actual cash flows, there can be up to a 6-month delay in issuance of currency creating havoc on importers' planned purchases. In response to currency regulations and economic/political instabilities, many international firms have taken steps to reduce their operational risk in Venezuela, some by completing exiting the market.

Company B's Disruption

Since 2005, Company B's sales have been increasing due to decreasing competition in Venezuela. However, as nationalization of international firms' oil assets in Venezuela intensified along with potential for currency devaluation, Company B decided to limit the exposure to risk by moving all inventory from in-country through attrition by October 2007. Customers were then required to purchase product in the United States and provide shipping to Venezuela. This moved the risks to trading partners and caused slight cost increases due to inefficiencies in shipping, combined with lower customer services levels due to off-shore warehousing. Although effective in reducing corporate risk, the CADIVI program continued to hamper the importers' ability to obtain needed currency when required, creating, for example, zero orders from all Venezuelan customers for a particular month in early 2008. Company B's policy for advanced payment combined with delays in importers obtaining US dollars made planning for efficient supply chain operations impossible. Obtaining foreign currency on

the secondary market (i.e. non-preferred dollars outside of the CADIVI program) increased costs by buying US dollars at 3-times the preferred exchange rates, significantly impacting the profitability of operations. Due to these issues, Company B and wholesale customers were operating at loss despite increase demand for their products in Venezuela.

Alignment of Revenue Forecasts with Procurement Forecasts
Company B, Disruption #4
(B4 – Other: Communication disruption)

Product line of discussion represents a total of 250 SKUs, with 30 percent of these creating 90 percent of revenue. Error in alignment of quarterly revenue forecasts (in dollars) with the procurement forecast (in quantity by SKU) caused a significant stock-out for an entire region of customers. Both of these forecasting duties were assigned to the same office; however, no checks-and-balances were in place to ensure accuracy. A recent staffing change left a single individual responsible, who was unfamiliar with the process. In fact, manual adjustments to the forecast were typically made by financial staff without feedback to the forecast "owner" or to the procurement office.

Errors in forecast alignment were not noticed until the regional sales manager entered large orders to satisfy his quarterly quota (see Company B, Disruption #2) and was informed by warehouse staff that the requested product was not available. A manual comparison between the sales forecast ($) and the procurement forecast (units) showed errors in original quarterly calculations. A total of $1.7 million in product was delayed to customers due to short procurement.

APPENDIX C

COMPANY C

Overview

Company C is a state-wide medical transportation firm operating as a non-profit in conjunction with several area hospitals. This study covers their medical supplies, drugs, medical equipment, vehicle parts and aviation fuels supply chains that supports their service-orientated mission. Services are provided to approximately 13,000 patients annually.

Assessment Results

Supply Chain Resilience Assessment
SCRAM 1.1

January 24, 2008

prepared by:

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from the

The Center for Resilience
and
Fisher College of Business
The Ohio State University

EXECUTIVE SUMMARY

This self-assessment was completed at the Company C, by a team of 12 individuals, from December 14, 2007 through January 2, 2008.

In a world of turbulent change, resilience is a key competency — since even the most carefully designed supply chain is susceptible to unforeseen factors. Businesses must be prepared to cope with a continuous stream of challenges, ranging from human errors to technological failures to natural disasters.

The Center for Resilience and the Fisher College of Business at The Ohio State University (OSU) have developed a new resilience framework to assist businesses deal with change: ***resilience*** is "the ability of an enterprise to survive, adapt and grow in the face of change and uncertainty." We created a tool for measuring resilience in a business enterprise – Supply Chain Resilience Assessment & Management (**SCRAM**) – to assess supply chain resilience in terms of two major dimensions:

- **Vulnerabilities** – fundamental factors that make an enterprise susceptible to disruptions
- **Capabilities** – attributes that enable an enterprise to anticipate and overcome disruptions

We define the Zone of Balanced Resilience as a balance between vulnerabilities and capabilities, where firms will be the most profitable in the long term.

This report includes detailed results of the assessment and recommendations. Significant recommendations are as follows:

- Overall resilience assessment appears to be an artifact of conflicting perspectives within the firm. Base Directors rate vulnerabilities significantly lower, while rating capabilities slightly higher than the Supply Staff. Base Directors reported a Resilience Gap of +27 percent, in Zone 3: Erosion of Profits, while Supply Staff reported a Resilience Gap of -14 percent, in Zone 2: Exposure to Risk. Managers and personnel from other support functions score in between these two extremes, reporting a Resilience Gap of +9 percent.
- Company C's greatest strength is its Market Position, specifically in Product Differentiation and Brand Image. Resources should be invested to protect this strength from the high levels of vulnerability to Deliberate Threats such as product Liability Claims and Direct Attacks as well as Sensitivity issues such as the Visibility of Errors to Stakeholders. Strict quality standards for procured materials, receiving inspections, proper storage, item-level tracking and strict training standards can reduce risks from these threats.
- Visibility is a weakness of concern under Company C's centralized inventory control system. In order for a centralized system to be effective, accurate and timely data must be readily available.

- Contingency Planning and Simulation should be greatly expanded to prepare for potential Pandemics, Natural Disasters and Terrorist Threats, all of which may impact Company C's capacity while drastically surging demand for services.
- The highest vulnerability facing Company C's supply chain is Sensitivity. The highest two rankings of the 40 sub-factors, Visibility of Disruptions to Stakeholder and Potential Safety Hazards, must be proactively managed. Strict training programs combined with periodic reviews and inspections are warranted.
- Supply chain vulnerabilities were rated significantly lower than expected for complex products such as medical supplies and equipment. Additional review is recommended.

Company C has taken an important first-step in exploring resilience. The Center for Resilience and the Fisher College of Business at The Ohio State University are dedicated to collaborating with Company C in future research, and commit to providing Company C with a consolidated benchmarking report due out in late summer 2008.

Assessment Results

Company C

Goals and Scope

The goal of the project is to create a baseline understanding of Company C's current level of Supply Chain Resilience. Through an understanding of resilience, recommendations to more effectively and efficiently manage enterprise capabilities can be identified when compared with the supply chain's inherent vulnerabilities. Therefore, the scope of the project is limited to the flow of goods supporting operational requirements: procurement, receiving, storage and issue of medical supplies, drugs, medical equipment, vehicle parts and aviation fuel. Customers are therefore defined as the personnel of Company C units who require the right items, at the right place, at the right time to service the end consumer. Products are the medical supplies, drugs, medical equipment, vehicle parts and aviation fuel. First tier suppliers are the procurement sources for all products, as no manufacturing is accomplished organically. Suppliers, however, as a general term are defined to include these first tier suppliers as well as all of their suppliers, component suppliers and raw material suppliers upstream in the supply chain. Not included in this scope are the services provided by Company C to transport patients, the medical care provided during transport or the maintenance and operation of the helicopter fleet.

Team Composition

The Company C Resilience Assessment Team was selected using a multi-level, cross-functional design. Membership from operational positions as well as senior-management is desired to provide coverage of both tactical and strategic issues. Additionally, including members from each functional specialty within the scope of the study ensures that the team comprises detailed experiences in each of the enterprise categories included in the broad framework of supply chain resilience. Review of the titles and functional roles confirm that the team composition adequately reflected the multi-level, cross-functional design. A total of 12 participants comprised the Resilience Assessment Team, with their functional roles depicted in Figure C.1.

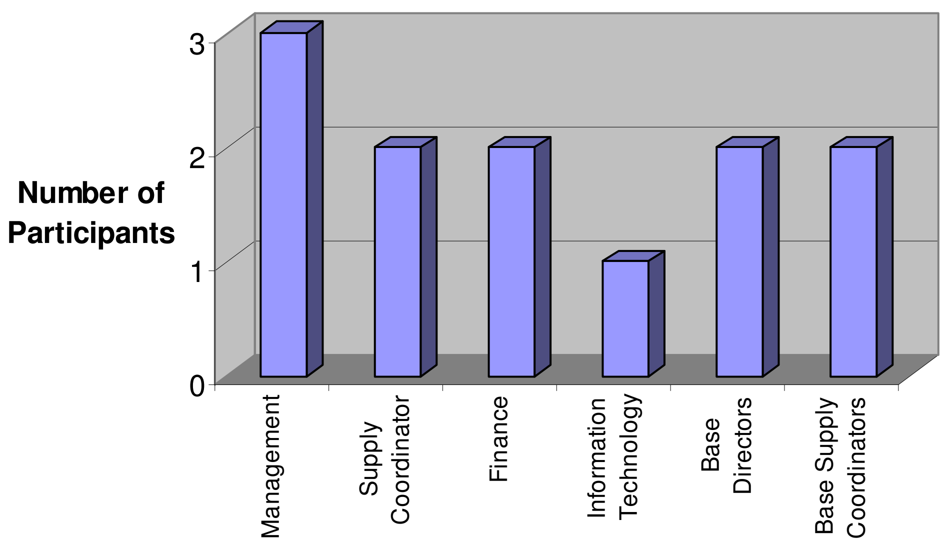

Figure C.1: Team Composition

Resilience Measurement

Each team member completed the secure, on-line assessment during the period of December 14, 2007 to January 2, 2008 – SCRAM 1.1: *Supply Chain Resilience and Management.* The average amount of time to complete the survey was 28.5 minutes per person. During the assessment, team members responded to questions on a Likert Scale of 1 to 5, representing responses from "Strongly Disagree" to "Strongly Agree". Responses were coded confidentially and reviewed for data accuracy. Team members were allowed to select "Don't Know" or leave questions blank to prevent inexperienced responses from biasing the results. A minimal number of these responses were recorded (Don't Know = 13 percent, Blank = 2 percent) which is consistent with similar studies, and in general they matched appropriately against the respondent's job title and functional area (e.g. an inventory clerk may not have detailed knowledge of corporate finances). One issue arose in data collection as high levels of between-subject variability were identified on questions regarding "the customer." Therefore, two individuals were contacted after the assessment to confirm their understand of "who" the customer of the study is (9 questions); responses were updated as necessary.

Analysis of the data began at the strategic level. Responses for each item were averaged to form Factor Scores for each of the 7 Vulnerability factors and 14 Capability factors. An overall measure of resilience was then obtained by comparing the balance between the vulnerability and capability grand averages. Overall, Company C's resilience assessment is in Zone 1, the Zone of Balanced Resilience, with only a slight imbalance toward excessive capabilities (score of 3.4) as compared to the current

vulnerabilities (score of 3.2). On average this equates to a small Resilience Gap of +4.5 percent; however, this appears to be an artifact of a contradiction between categories of functional experts (more details to follow). The assessment is graphically depicted in Figure C.2, with the composite score clearly indicated. Individual scores are fairly evenly clustered, with a single potentially outlying optimist (upper-right) from a customer-facing organization and a single potentially outlying pessimist (lower-right) from a supply-side organization.

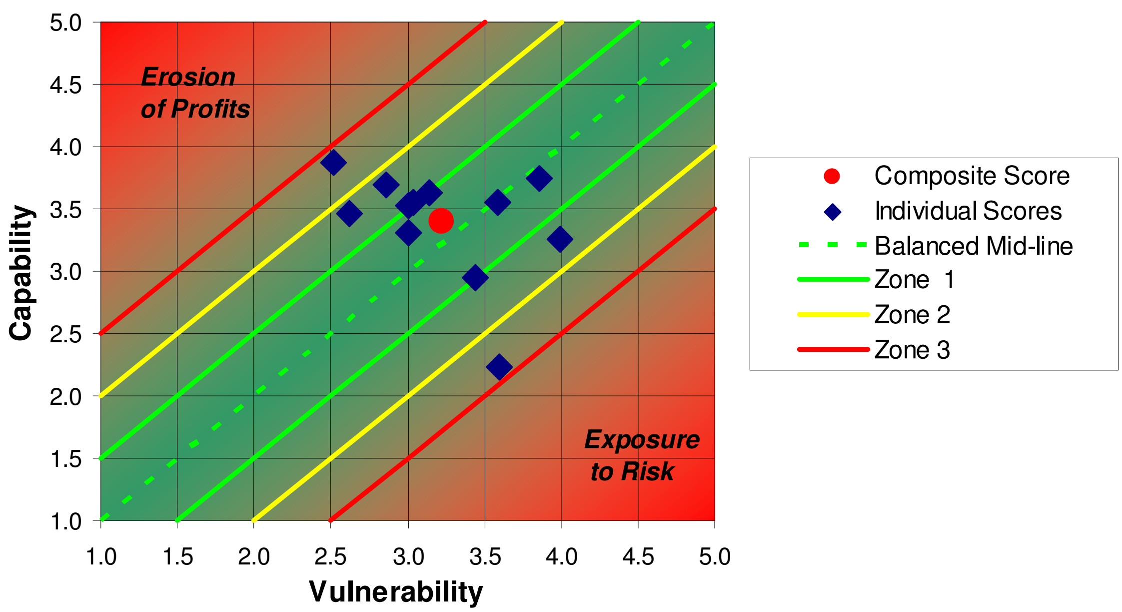

Figure C.2: Strategic Assessment Results

However, it is critical to note that in general the supply personnel (Supply Coordinators, Base Supply Coordinators) rated vulnerabilities significantly higher, 39.8 percent, over the more customer-facing roles of the Base Directors. These groups also

showed differences in capability scores with Base Directors rating management strengths 15.6 percent higher than the supply personnel. See Figure C.3 for this representation. These groups represent a conflicting view of the resilience of the enterprise: Base Directors with a Resilience Gap of +27 percent, in Zone 3 Erosion of Profits, while Supply personnel rate a Resilience Gap of -14 percent, in Zone 2 Exposure to Risk. (Senior managers and other functional experts are grouped on Figure C.3 for reference.) Significant attention should be directed to specific areas where differences in perceptions exist, and although all vulnerabilities showed positive perception gaps between these two groups, the most significant areas are in Supply Chain Vulnerabilities (+81 percent), Resource Limited (+63 percent) and Turbulence (+54 percent). Details of these differences will be addressed as they occur throughout the remainder of this report.

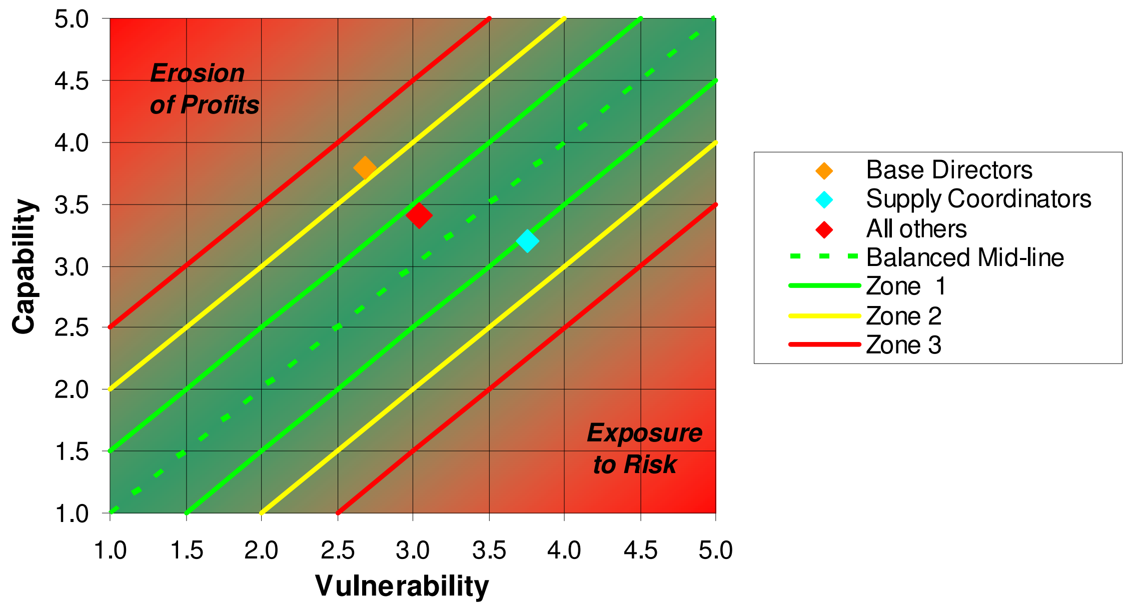

Figure C.3: Overview of Differences between Key Groups

The analysis continues with review of vulnerability findings, followed by capability findings with recommendations for capability improvements based on the current levels of vulnerabilities as appropriate.

Vulnerability Results

The SCRAM assessment provides a clear distinction between high and low vulnerabilities. Overall, the responses are indicative of an operation with strictly controlled products and processes, while facing strong external pressures from governmental regulations and competition. A summary of the scores and rankings are shown in Table C.1 and Figure C.4, while detailed sub-factor scoring is presented in Table C.3, listed at the end of this report. Sensitivity, External Pressures and

Connectivity are the top issues facing Company C. The team identified the overall most vulnerable item as Sensitivity: the importance of carefully controlled conditions for product and process integrity. Four of the top 10 sub-factors are Sensitivity issues: errors are extremely visible to stakeholders (patients, medical providers, insurance companies and the general public), operating conditions can be dangerous, proper storage of products is essential and the quality of products is critical. Company C should focus attention on strict training and certification programs, to include drills and managerial gaming which later receive more detailed critiques.

Here it is important to highlight the differences in perceptions between two of the groups of participants in regards to Sensitivity. Supply Coordinators gave 20 to 30 percent more emphasis to the vulnerabilities of Brand Image of Supplies, Regulation and Restrictions, and the Level of Concentration and Inter-dependence of Suppliers. An example of Brand Image of Supplies: product quality issues occur at another medical facility in the United States which immediately bans Company C's entire stock of that particular item. An example of Concentration of Suppliers is a natural disaster at a major supplier's warehouse which stops product deliveries for months. Management at Company C must address these issues of management perception gaps to ensure that adequate resources are placed against these vulnerabilities.

Ranking	Vulnerability	Factor Label	Average Score
1	Sensitivity	V5	3.89
2	External Pressures	V3	3.64
3	Connectivity	V6	3.39
4	Turbulence	V1	3.08
5	Resource Limits	V4	2.99
6	Deliberate Threats	V2	2.85
7	Supply chain vulnerabilities	V7	2.67

Table C.1: Vulnerability Rankings

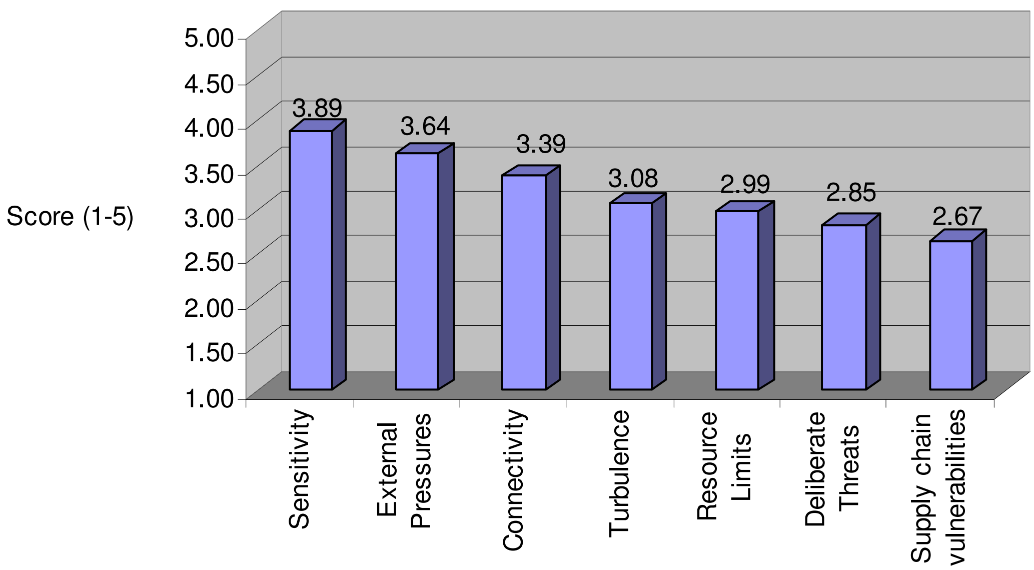

Figure C.4: Vulnerability Scores

The second-ranked vulnerability is External Pressures, which are influences, not specifically targeting the firm, that create business constraints or barriers. In this area, all sub-factors are rated highly vulnerable: from Government Regulations, to Competitive

Innovation and Price Pressures. In such an environment, a firm must maintain close relationships with supply partners and key customers, as well as government regulators. An active Business Intelligence program is critical to anticipate market shifts and innovations. Although none of the External Pressure sub-factors ranked in the top 10, 5 of the 6 sub-factors are ranked in the next tier.

Third, Connectivity is a strong vulnerability for Company C – the degree of interdependence and reliance on outside entities. This factor is driven by two areas of concern: Reliance on Information Flow and Reliance on Specialty Sources. First, information flow is critical to accurate, timely data on operations and assets. Without accurate visibility of inventories at dispersed locations, a firm will typically face recurring stock-outs followed by over-stocks resulting in reduced customer service and higher costs. Second, specialty sources restrict flexibility in procurement and therefore demand closer relationships with suppliers. Supplier Relationship Management should go beyond establishing guidelines for the ordering process and include product development initiatives, quality control feedback and risk and profit sharing arrangements. This close relationship opens other opportunities for implementation of programs such as Vendor Managed Inventory and Electronic Data Interchange (EDI) to include real-time sharing of Point-of-Sale (POS) data.

As noted previously, there is a significant difference in perceptions between Base Directors and Supply Coordinators. In the area of Connectivity, Supply Coordinators rated their vulnerability to products from a global supply chain (Scale and Extent of the Supply Chain) as 2.3 points higher than the Base Directors (on a 5 point scale). It

appears that the Base Directors are not adequately informed of the complexity of the supply chain and the vulnerability that is created by the potentially thousands of links and nodes of a global supply chain.

Turbulence was ranked moderately in relation to other vulnerabilities. This factor received a very wide spread of scores from very high (Pandemic and Unpredictability in Customer Demand) to very low (Fluctuation in Prices and Exposure to Geopolitical Disruptions). Separating these factors highlights the urgency for Company C to prepare for the extreme surge in demand that would be generated by a pandemic or terrorist action. Safety stock of materials can be a front-line defense to surges in demand; however, less expensive options should be considered in conjunction with Capacity: Collaboration with providers in other geographic areas, Organizational factors such as cross-training of employees and Efficiency improvements to patient handling and patient change-overs that can be improved through process design, training and realistic response exercises.

Supply Chain Vulnerabilities were rated relatively low. Despite responses which indicated that the products procured by Company C come from a global, interconnected supply chain, team members may not be fully aware of their vulnerability to their suppliers. On the contrary, however, Company C may have partnered with very resilient suppliers which create low threat of supplier disruptions. However, the supply chain functional experts reported Supplier Vulnerabilities as 2 full points higher than the Base Directors, who may be buffered from supplier disruptions by Company C's own inventories and recovery actions (e.g., response of "Agree" to the question: "Our

suppliers frequently face significant disruptions," as compared to "Disagree"). Management should review their requirements, their capabilities and the capabilities of key suppliers in relation to the costs involved and consider potential cost saving initiatives in collaboration with suppliers.

Following the assessment of each factor, each team member was asked to report their perception of the relative importance of each of the measures. These questions were reserved for the end of the assessment to ensure that respondents were exposed to each of the vulnerability and capability factors in order to better determine their relative priorities. Results of the relative importance of vulnerabilities are shown in Figure C.5. A single vulnerability factors stands out as most critical: External Pressures. Company C should concentrate on maintaining existing capabilities and improving new capabilities to anticipate and manage these issues as mentioned previously. It is interesting to note that the importance of Turbulence was rated as only "Important," despite the volatility of demand and the short-notice for transport services. This indicated that the medical supplies and equipment requirements are relatively predictable. With very strong concerns about threats from a pandemic (scores rated 3rd of 40 sub-factors) and terrorism and sabotage (8^{th} of 40), Company C should consider reviewing its priorities in regards to these sub-factors which reported relatively low priorities (importance ratings of 3.0 and 3.5, respectively on a 5-point scale). Both types of disasters may directly affect Company C's labor force and assets, but will definitely surge demand well beyond normal capacity for medical services.

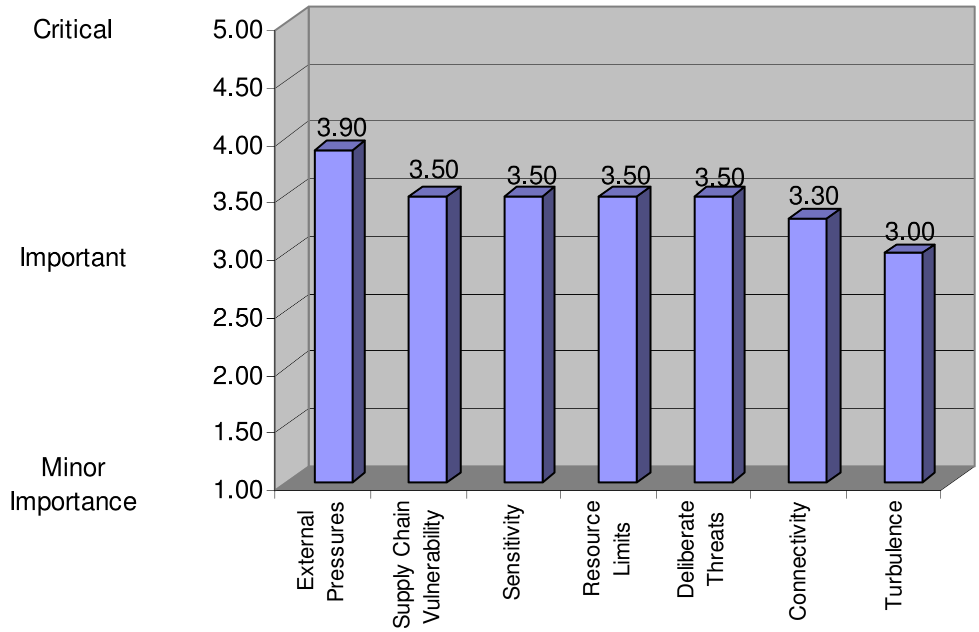

Figure C.5: Importance of Vulnerabilities

As vulnerabilities represent the fundamental factors that make an enterprise susceptible to disruptions, these factors are considered inherent in the enterprise's operating environment and therefore can not be affected in the short term. In the long term, strategic decisions altering the environment will radically change the supply chain, which would then require a re-evaluation. Therefore, tactical recommendations will be targeted to the capability scores, which are the methods that an enterprise can utilize to anticipate and overcome disruptions.

Capability Results

In order to combat vulnerabilities, research has shown that a supply chain must have the capability to overcome its vulnerabilities for long-term survival. These supply

chain capabilities create the ability to anticipate and potentially prevent a disruption, mitigate the effects of a disruption or adapt with new, more profitable processes, products or services. Table C.2 and Figure C.5 summarize the capability scores for Company C's self-assessment. Detailed sub-factor rankings are presented in Table C.4, listed at the end of this report.

Ranking	**Capability**	**Factor Label**	**Average Score**
1	Market Position	C12	4.10
2	Financial Strength	C14	3.70
3	Recovery	C8	3.67
4	Efficiency	C4	3.64
5	Capacity	C3	3.64
6	Security	C13	3.52
7	Organization	C11	3.44
8	Anticipation	C7	3.34
9	Dispersion	C9	3.29
10	Adaptability	C6	3.21
11	Flexibility in Order Fulfillment	C2	3.17
12	Flexibility in Sourcing	C1	3.07
13	Visibility	C5	3.03
14	Collaboration	C10	2.49

Table C.2: Capability Rankings

Company C's Resilience Team reported their strongest capability as Market Position: the status of the company and its products in specific markets. Scores were high in areas such as Product Differentiation and Brand Image. This factor may be difficult to maintain in a more competitive environment. Communicating the value of

Company C's quality products and services to customers is critical to maintaining the price-premium that such product differentiation requires, especially if market share is attacked by competitors.

Financial Strength is ranked second and led by Insurance Coverage. Obviously a critical concern in the medical field; this however, must be balanced by the level of risk aversion of the stakeholders as compared with the capabilities provided. For example, in relation to medical, equipment, an effective Supplier Relationship Management process can identify and communicate potentially hazardous or ineffectual products for remediation efforts prior to causing actual damage to customers, thus lowering the risk of product liability. In addition, strong capabilities of Financial Reserves and Liquidity must be supported by appropriate Price Margins. Additional strengths are well balanced with Recovery, Efficiency, Capacity and Security.

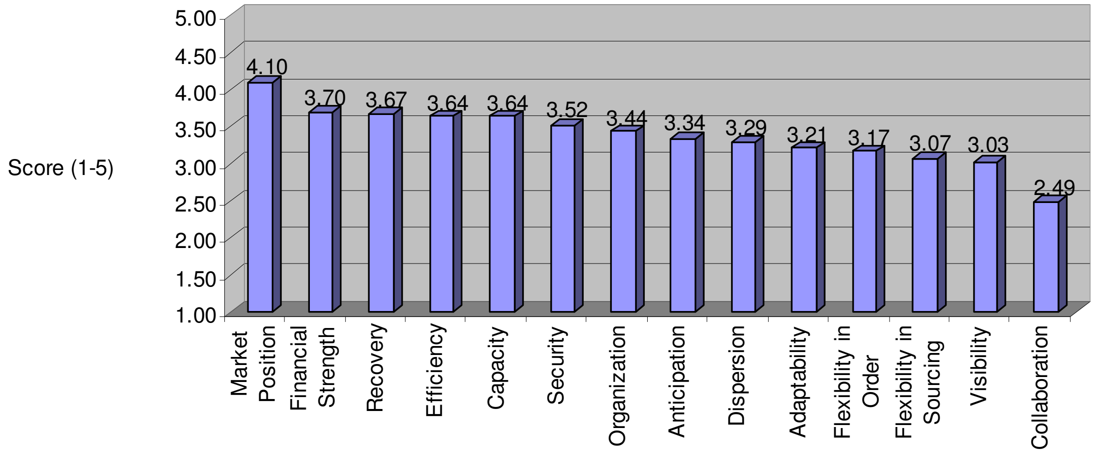

Figure C.6: Capability Scores

On the opposite extreme, Company C's lowest capability scores are in Collaboration, Visibility, Flexibility in Sourcing and Flexibility in Order Fulfillment. First, Collaboration: the ability to work effectively with other entities for mutual benefit should be a major area of concern in Company C's very Sensitive operations. The team scored Information Sharing with Partners as the lowest of all 71 capability sub-factors. In order to improve Collaboration, Company C must first collect accurate and timely inventory data (improved Visibility), then institute effective Electronic Data Interchange (EDI) procedures with key suppliers. As procurement is highly consolidated among key suppliers, this initial expense should be relatively low and can provide immediate and significant returns on investment. Some initiatives have seen suppliers funding such Collaboration in order to reduce their inventory and order costs. Once established, Collaborative Forecasting and Risk Sharing programs, both currently in the bottom 10 capabilities, can then be implemented to further improve inventory availability while

reducing costs. As Company C procures goods from a limited number of large distributors, these suppliers will have visibility of a much large pool of demand and are better positioned to make more accurate forecasting decisions. In addition, although medical crews may not be able to Postpone Orders, efforts to identify suitable substitutes in terms of alternate suppliers and product interchangeability can greatly increase inventory availability without massive amounts of stock. As a final comment on Collaboration, Company C may consider programs such as Vendor Managed Inventory (VMI) and Direct Delivery where appropriate. By further consolidating stocks into regional warehouses, coupled with very short delivery lead-times, a vendor's carrying costs may decrease substantially and more than offset potential increases in distribution costs. In view of the significant vulnerability to Connectivity, these issues should be addressed immediately.

Visibility is another major concern for Company C – knowledge of the status of operating assets and the environment. Currently, there are no strong technology solutions in-place as the team reported that not all data on assets, equipment and employees is accurate or timely. Current methods of inventory management are very labor intensive, and with a moderate investment in technology such as bar-coding and/or Radio Frequency Identification (RFID), significant improvements in Visibility can be made quickly and be maintained with little expense. As costs continue to decrease, RFID technologies would be a very successful application for tracking high-value equipment that moves frequently between locations and requires periodic calibration and testing – knowing where your assets are located without repetitive manpower can be very cost-

effective. Visibility begins internally and then should be managed in conjunction with the Collaboration issues mentioned above. Additionally, more aggressive Business Intelligence and Market Research programs may successfully address vulnerabilities to Competitive Innovations.

Company C's moderate set of Anticipation programs should be continued, which are evidenced in high scores for Recognition of Early Warning Signals and Monitoring of Deviations. However, greater emphasis is recommended for Risk Identification and Contingency Planning. With improved Visibility, data available to risk assessments will be improved and contingency planning will more accurately reflect operations.

Finally, Flexibility in Sourcing and Flexibility in Order Fulfillment was rated significantly low. Company C should work with suppliers to ensure that sufficient capacity is available to meet peak demands and allow flexibility when one source or mode of delivery is disrupted for any reason. Although many medical supply items and drugs are strictly controlled by external policies, Company C should constantly review items that can fill multiple uses to allow for consolidation of inventory. Medical equipment that performs the roles of several existing pieces of equipment can also be beneficial. Look for designs that include modular technologies, especially when user replacement of faulty components is authorized, in order to reduce life-cycle costs and increase availability of assets. For any single type of item, consolidation of equipment from various vendors or incompatible versions may further reduce spare parts required in inventory and reduce training requirements for maintenance staff. New collaborative procurement arrangements must contain the capability for Peak versus Base-level

Ordering. Also, consider supplier metrics that segregate routine orders and emergency orders to reduce costs on basic items while maintaining the highest standards for critical items. Although current Demand Pooling was rated as a strength in this area, further reductions in inventory may be possible through even greater pooling as mentioned previously.

Analyzing the importance of the 14 Capability factors provides interesting insight into the relative priorities that should be placed on each area, see Figure C.7. Company C is most focused on Financial Strength and Recovery when disruptions do occur; however, this should not be overemphasized based on the expense of carrying excess Capacity of equipment and supplies if more flexible options are available. A serious concern is the importance placed on Visibility, Flexibility in Order Fulfillment and Capacity. Without appropriate awareness of assets or the timely ability to acquire new assets, Anticipation and Recovery programs will be ineffectual.

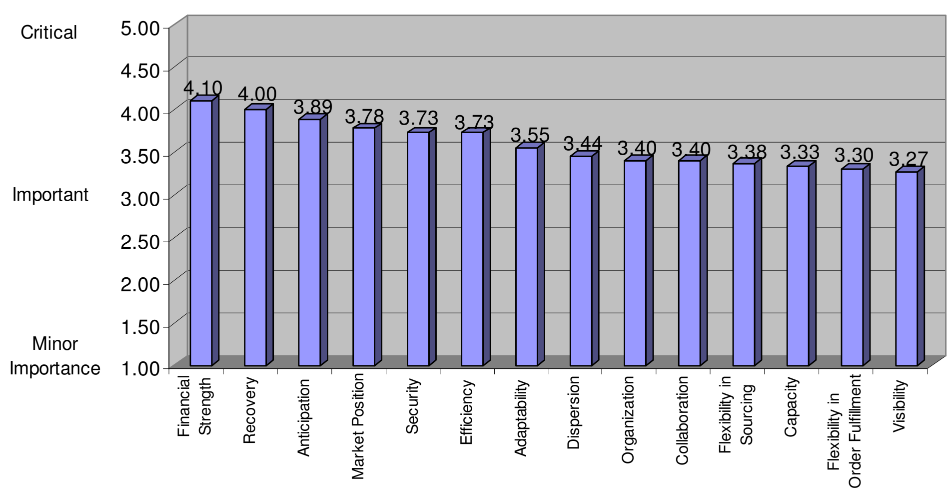

Figure C.7: Importance of Capabilities

Resilience Recommendations

Company C is commended for compiling an excellent Resilience Assessment Team. The team's composition matched well with the scope and goals determined by the project leaders. Through the team's investment in approximately 10 man-hours, a significant number of important issues were uncovered and discussed in this report. A summary follows:

- Resilience Gap between two main groups indicates management concern: +27 percent and -14 percent, both outside of the Zone of Balanced Resilience, shows conflicting perspectives of resilience between Base Directors and logistics personnel.
- Adequately communicate Company C's value to customers in order to maintain an appropriate price-premium.
- Maintain strict quality standards to protect Brand Image and Price Margins.
- Review operating Insurance Coverage based on internal capabilities and risk aversion.
- Emphasize Risk Identification and Contingency Planning.
- Improve Visibility of assets.
- Enhance Collaboration with key suppliers to improve availability and reduce costs. Consider implementing EDI systems, demand pooling and collaborative forecasting.
- Add Simulation and Gaming Exercises into existing network design processes. Gaming can be an effective method of realistic practice, especially for managerial command and control.
- Further evaluate Supplier Vulnerabilities in more detail to reduce risk from supplier disruptions or shifting risk to more capable suppliers.

Follow-on studies at the Center for Resilience and the Fisher College of Business are currently being conducted to empirically validate more tactical recommends than

those appearing in this text, as well as benchmarking between firms to gain greater fidelity to your assessment. To assist in accomplishing this effort, historical demand and performance data covering the time-period of this study was collected at Company C. The research team will provide this consolidated benchmarking report in late summer 2008 in order to assist Company C to further integrate resilience concepts into management improvement programs.

Rank	Average	Item	Title
1	4.78	V5.7	Visibility of disruption to stakeholders
2	4.58	V5.6	Potential safety hazards
3	4.55	V1.6	Pandemic
4	4.50	V2.6	Product liability
5	4.25	V5.3	Fragility
6	4.17	V6.4	Reliance upon information flow
7	4.09	V5.2	Importance of product purity
8	3.91	V2.1	Terrorism & sabotage
9	3.83	V3.2	Government regulations
10	3.75	V6.3	Reliance upon specialty sources
11	3.73	V3.1	Competitive innovation
12	3.73	V3.3	Price pressures
13	3.73	V5.1	Utilization of restricted materials
14	3.70	V1.1	Unpredictability in customer demand
15	3.67	V5.5	Reliability of equipment
16	3.64	V3.4	Corporate responsibility
17	3.64	V5.4	Complexity of process operations
18	3.64	V5.8	Symbolic profile of brand
19	3.55	V3.6	Environmental changes
20	3.50	V4.6	Human resources
21	3.36	V4.2	Production capacity
22	3.36	V4.3	Distribution capacity
23	3.27	V3.5	Social/Cultural changes
24	2.90	V5.9	Concentration of capacity
25	2.90	V6.1	Scale and Extent of supply network
26	2.90	V7.1	Supplier vulnerabilities
27	2.82	V4.1	Supplier capacity
28	2.82	V4.5	Utilities availability
29	2.78	V6.5	Degree of Outsourcing
30	2.70	V1.5	Unforeseen technology failures
31	2.67	V6.2	Import/export channels
32	2.64	V1.4	Exposure to natural disasters
33	2.58	V7.2	Customer vulnerabilities
34	2.50	V2.5	Industrial espionage
35	2.45	V1.2	Fluctuations in currencies & prices
36	2.45	V4.4	Raw material availability
37	2.27	V2.2	Piracy & theft
38	2.22	V1.3	Exposure to geopolitical disruptions
39	2.09	V2.4	Special interest groups
40	2.00	V2.3	Union activities

Table C.3: Vulnerabilities by Score Rank

Rank	Average	Item	Title
1	4.36	C12.4	Product differentiation
2	4.25	C12.1	Brand equity
3	4.09	C4.4	Product/part variability reduction
4	4.08	C12.2	Customer loyalty/retention
5	4.00	C9.5	Geographic dispersion of markets
6	4.00	C4.5	Failure prevention
7	4.00	C14.3	Insurance coverage
8	4.00	C12.6	Communications
9	4.00	C12.5	Relationships
10	4.00	C11.6	Culture of caring for employees
11	3.92	C3.1	Backup energy sources/communications
12	3.89	C12.3	Market share
13	3.82	C8.1	Resource mobilization
14	3.75	C8.3	Crisis management
15	3.75	C11.5	Benchmarking/ Feedback – Learning
16	3.73	C13.2	Access restriction
17	3.73	C11.1	Creative problem solving culture
18	3.71	C14.2	Portfolio diversification
19	3.70	C2.3	Demand pooling
20	3.67	C7.4	Recognition of early warning signals
21	3.67	C14.1	Financial reserves & liquidity
22	3.64	C13.3	Employee involvement in security
23	3.58	C8.2	Communications strategy
24	3.57	C14.4	Price margin
25	3.56	C7.3	Monitoring & Communicating deviations & near
26	3.56	C4.3	Waste elimination
27	3.56	C13.5	Cyber-security
28	3.55	C3.2	Redundancy (Assets, labor)
29	3.50	C9.2	Distributed capacity & assets
30	3.50	C8.4	Consequence mitigation
31	3.50	C2.6	Reallocation
32	3.50	C13.1	Layered defenses
33	3.50	C11.3	Diversity of skills & experience
34	3.44	C3.3	Reserve capacity (Materials, assets, labor)
35	3.44	C13.4	Collaboration with governments
36	3.44	C1.5	Alternate suppliers/Outsourcing options
37	3.40	C7.1	Demand forecasting methods
38	3.36	C6.6	Learning from experience
39	3.33	C9.4	Location-specific empowerment

Continued

Table C.4: Capabilities by Score Rank

Table C.4 continued

Rank	Average	Item	Title
40	3.33	C6.4	Alternative technology development
41	3.33	C1.4	Supply contract flexibility
42	3.30	C6.3	Seizing advantage from disruptions
43	3.27	C7.6	Recognition of opportunities
44	3.27	C2.5	Alternate distribution channels
45	3.20	C6.1	Fast re-routing of requirements
46	3.20	C4.1	Labor productivity
47	3.18	C4.2	Asset utilization
48	3.17	C5.1	Information technology
49	3.17	C11.2	Accountability
50	3.14	C10.4	Product life cycle management
51	3.11	C5.4	Business intelligence gathering
52	3.10	C7.2	Risk identification & prioritization
53	3.10	C6.5	Lead time reduction
54	3.00	C9.1	Decentralization of key resources
55	3.00	C7.5	Contingency planning/Preparedness
56	3.00	C2.1	Multi-sourcing (peak vs. base)
57	2.91	C5.3	Collaborative information exchange
58	2.91	C5.2	Products, Assets, People
59	2.89	C13.6	Personnel security
60	2.67	C1.2	Product/service modularity
61	2.63	C6.2	Strategic gaming & simulation
62	2.58	C11.4	Substitute leadership capacity
63	2.57	C10.1	Collaborative forecasting
64	2.57	C1.1	Common product platforms
65	2.56	C1.3	Multiple pathways & skills
66	2.50	C9.3	Distributed leadership
67	2.50	C10.3	Postponement of orders
68	2.45	C2.4	Inventory management
69	2.38	C10.5	Risk sharing with partners
70	2.33	C2.2	Delayed commitment/Production postponement
71	2.14	C10.2	Transparency – information sharing

APPENDIX D

COMPANY D

Overview

Company D is a major division of a global chemical company. Company D's products are primarily used by the petrochemical refining industry and has sales in the range of $40 billion annually. Manufacturing plants are located in the United States and Europe with a concentration in the Mexican Gulf region. Company D has a world-wide market for its products.

Assessment Results: Company D

Supply Chain Resilience Assessment and Management SCRAM™ 1.1

February 21, 2008

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EXECUTIVE SUMMARY

This self-assessment was completed at Company D, by a team of 36 individuals, during the period of January 29 to February 12, 2008.

In a world of turbulent change, resilience is a key competency, since even the most carefully designed supply chain is susceptible to unforeseen factors. Businesses must be prepared to cope with a continuous stream of challenges, ranging from human errors to technological failures to natural disasters.

The Center for Resilience and the Fisher College of Business at The Ohio State University (OSU) have developed a new resilience framework to help businesses deal with change: ***resilience*** is "the ability of an enterprise to survive, adapt and grow in the face of change and uncertainty." We created a tool for measuring resilience in a business enterprise – Supply Chain Resilience Assessment & Management (**SCRAM**™) – to assess supply chain resilience in terms of two major dimensions:

- **Vulnerabilities** – fundamental factors that make an enterprise susceptible to disruptions
- **Capabilities** – attributes that enable an enterprise to anticipate and overcome disruptions

We define the Zone of Balanced Resilience as a state of balance between vulnerabilities and capabilities, where firms will achieve both long term profitability and protection against disruptions.

This report includes detailed results of the assessment and recommendations. Significant recommendations are as follows:

- Company D's strongest capabilities are Security, Market Position and Financial Strength. Specific areas of strengths are a broad dispersion of markets, brand equity and cyber security.
- The highest vulnerability facing Company D is Connectivity, followed by Sensitivity and External Pressures. Connectivity threats may be addressed through effective Visibility and Collaboration capabilities.
- However, Collaboration is a weakness of concern under Company D's centralized production system. Based on a lack of capability for customers to postpone orders, Company D should look for ways to forward locate stock and justify to customers the added value of a resilient supply chain in order to recoup the additional costs of excess inventory, rapid transportation and/or flexible production.
- Capacity, Flexibility in Sourcing and Flexibility in Order Fulfillment are also weaknesses and may represent factors inherent in a process manufacturing industry. With very high value assets, it may be more cost-effective to increase Flexibility in

Order Fulfillment than maintain excess production capacity or improve Flexibility in Sourcing without additional Capacity.

Company D has taken an important first-step in exploring resilience. The Center for Resilience and the Fisher College of Business at The Ohio State University have agreed to conduct a more detailed Phase II follow-up with Company D. The deliverables of this activity will include an action plan for ensuring supply chain resilience.

Assessment Results

Company D

Goals and Scope

The goal of the project is to create a baseline understanding of Company D's current level of Supply Chain Resilience. Based on this understanding of resilience, it is possible to develop enterprise capabilities that match effectively with the supply chain's inherent vulnerabilities. The scope of the project covers operations of the following business segments: Natural Gas Processing, Petrochemical Processing, Refining, Tail Gas Treating, Gasification, Flue Gas Treating and Landfill Treatment. Customers are only those companies or individuals that Company D sells to directly, typically *not* the end consumer. Suppliers are the set of first-tier organizations outside of Company D that provide raw materials, components, equipment and services.

Team Composition

The Company D Resilience Assessment Team was selected using a multi-level, cross-functional design. It included operational positions as well as senior management in order to provide coverage of both tactical and strategic issues. Additionally, the team included members from each functional specialty within the scope of the study to ensure coverage across the broad framework of supply chain resilience. A total of 36 participants comprised the Resilience Assessment Team, with their functional roles depicted in Figure D.1. Two members provided incomplete data and were omitted, resulting in a total of 34 subjects for analysis.

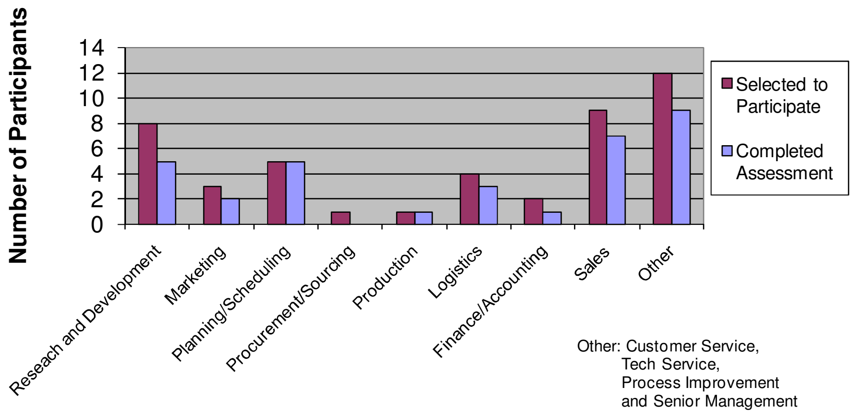

Figure D.1: Participants by Functional Area

Resilience Measurement

SCRAM™ 1.1: *Supply Chain Resilience Assessment and Management* assesses a firm's current *Portfolio of Capabilities* and facilitates matching of capabilities to the enterprise's *Pattern of Vulnerabilities*. Each team member completed a secure, on-line assessment during the period of January 29 to February 12, 2008. The average amount of time to complete the survey was 27.0 minutes per person. During the assessment, team members responded to questions on a Likert Scale of 1 to 5, representing responses from "Strongly Disagree" to "Strongly Agree". Team members were allowed to select "Don't Know" or leave questions blank to prevent inexperienced responses from biasing the results. A minimal number of these responses were recorded (Don't Know = 17 percent, Blank = 1 percent), which is consistent with similar studies, and in general they matched appropriately against the respondent's job title and functional area (e.g. an inventory

clerk may not have detailed knowledge of corporate finances). Participants were generally consistent in responses even between functional areas, excepted as noted below.

Analysis of the data began at the strategic level. Responses for each item were averaged to form Factor Scores for each of the 7 Vulnerability factors and 14 Capability factors. An overall measure of resilience was then obtained by comparing the balance between the vulnerability and capability grand averages. Overall, Company D's resilience assessment results scored the consolidated capabilities at 3.44 (on a scale of 1 to 5) as compared to current vulnerabilities at 3.15. The assessment is graphically depicted in Figure D.2, with the composite score indicated. Individual scores show a relatively broad spread along both axes.

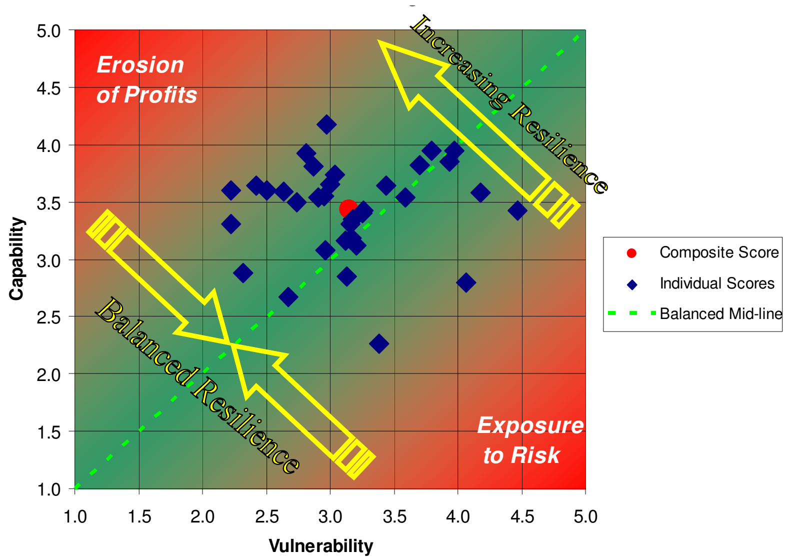

Figure D.2: Strategic Assessment Results

The following sections provide a review of vulnerability findings, capability findings and recommendations for capability improvements based on the current levels of vulnerabilities.

Vulnerability Results

The SCRAM™ assessment provides a clear distinction between high and low vulnerabilities. Overall, the responses are indicative of a global supply chain (high Connectivity) with very sensitive products and processes (high Sensitivity). In addition, high levels of External Pressures are noted in the areas of environmental issues, price pressures, competitive innovation and governmental regulations. A summary of the scores and rankings are shown in Table D.1 and Figure D.3, while detailed sub-factor scoring is presented in Table D.3, listed at the end of this report.

Ranking	Vulnerability	Factor Label	Average Score	Standard Deviation
1	Connectivity	V6	3.68	0.51
2	Sensitivity	V5	3.51	0.61
3	External Pressures	V3	3.43	0.64
4	Resource Limits	V4	3.17	0.74
5	Supplier/Customer Disruptions	V7	2.92	0.89
6	Turbulence	V1	2.88	0.85
7	Deliberate Threats	V2	2.25	0.87

Table D.1: Vulnerability Rankings

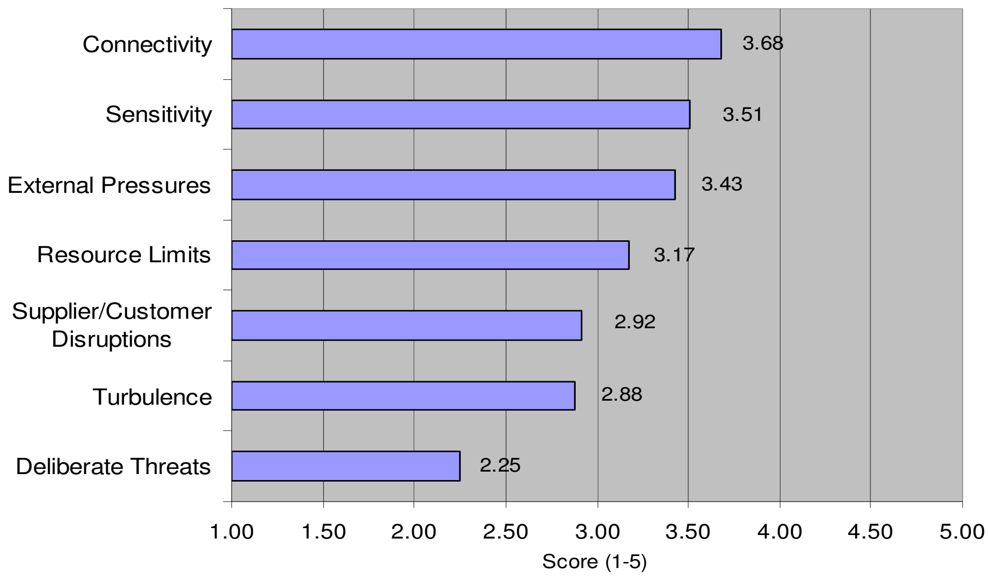

Figure D.3: Vulnerability Scores

The team identified the overall most vulnerable item as Connectivity: the degree of interdependence and reliance on outside entities. Three of the top 10 sub-factors are Connectivity issues, which are reliance on information flow, extent of import/export channels and reliance on specialty sources. The implication is that Company D should focus attention on Visibility and Collaboration capabilities such as improved data sharing and collaborative uses of shared information. A strong (negative) correlation exists between Collaboration and Connectivity, as team members consistently reported low Collaboration scores and high Connectivity scores (see Figure D.4). The major contributor of this trend is several very low Collaborative Information Sharing ratings

and a relatively consistent high ratings for Reliance upon Information Flow (see Figure D.5).

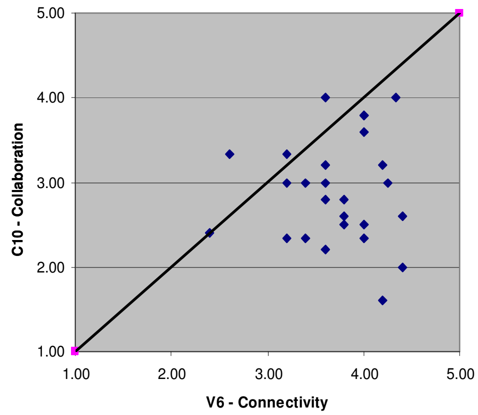

Figure D.4: Collaboration vs. Connectivity

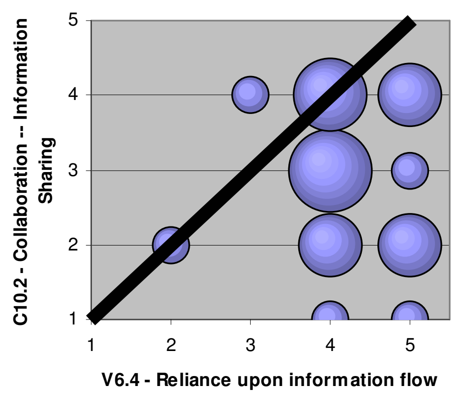

Figure D.5: Collaborative Info Sharing vs. Reliance upon Information Flow

The second-ranked vulnerability is Sensitivity, which means that Company D is dependent on carefully controlled conditions for product and process integrity. In this

area, the symbolic profile of the brands and the concentration of production capacity ranked significantly high. As expected, the purity of products and the use of restricted or controlled materials is also a high vulnerability. In such an environment, a firm must maintain strict quality control of processes and protect facilities, especially where bottlenecks are present. With the reliance on restricted materials, improvements in Flexibility in Sourcing will provide benefits whenever key suppliers have production delays or product quality issues.

Third, External Pressures are evident in Company D's operations. Issues relating to environmental concerns and price pressures both ranked in the top 10 of 40 vulnerability sub-factors. A strength that counteracts environmental concerns is waste elimination – a Top 10 capability. However, an active business intelligence program is critical to anticipate price pressures from market shifts, regulatory changes and product innovations – this was rated as a Bottom 10 capability. Business intelligence was rated as a much higher capability by Marketing and Customer Service team members (see Figure D.6), as compared to very low scores given by Logistics and Management members. Compounding this anomaly, the reverse is true of scores related to the threat from competitive innovations, viewed lower by Marketing and higher by Logistics and Management.

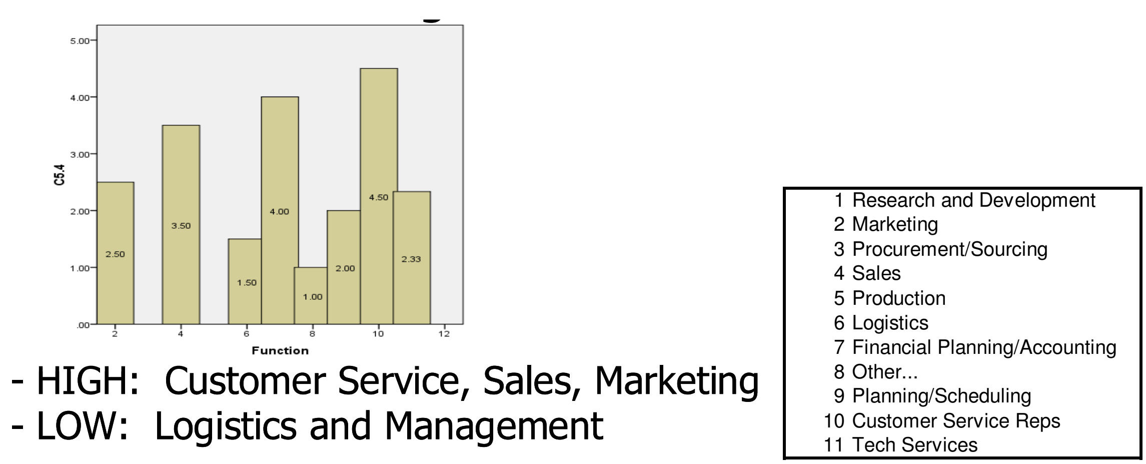

Figure D.6: Business Intelligence by Functional Area

In addition, procurement, production and distribution efficiencies can combat price pressures for existing products. Threats from competitive innovations also rank as a significant vulnerability, while Adaptability in alternative technology development is only moderate. Investments in product research and development and process improvements can combine to create a more flexible process to get new products to the market faster than competitors. Government regulations are understandably a critical vulnerability that Company D has balanced with a Top 10 capability of collaboration with government regulators.

Of note is the relatively low ranking of Turbulence, which is dominated by a single sub-factor of unpredictability in demand, with the five other sub-factors all rated "Neutral" or below. This poses the question of whether Company D's global markets face Turbulence more than reported, or if the capabilities created by the organization are

successful in mitigating the effects of turbulent change. In regards to the unpredictability in demand, safety stock of materials can be a front-line defense to surges in demand. However, this buffer used as a single responsive capability would become extremely expensive based on Company D's product lines and the dispersed markets. Therefore, Company D should consider a better balance of inventory with potentially less expensive options of minimal excess capacity and increased flexibility in distribution. Selling the value of such a reliable system to Company D's customers will be critical in maintaining high price margins and creating a source of competitive advantage based on customers' high costs of shut-down.

A final note of interest is in the vulnerability to Turbulence. There is a significant disparity between functional groups in two areas. First, Pandemics were viewed as a very low vulnerability (1.4 of 5) by the customer-facing participants of Sales and Marketing, while the Production and Logistics personnel rated the threat from a Pandemic as high (4.0 of 5). Second, despite significant concentration of production facilities in the Gulf Coast region, production-oriented personnel rated the vulnerability to natural disasters relatively low (1.75 of 5) while Sales personnel reported a greater threat from natural disasters that could disrupt product flow (3.25 of 5).

Following the assessment of each factor, each team member was asked to report their perception of the relative importance of each of the measures. These questions were reserved for the end of the assessment to ensure that respondents were exposed to each of the vulnerability and capability factors in order to better determine their relative priorities. Results of the relative importance of vulnerabilities are shown in Figure D.7.

Two vulnerability factors stand out as most critical: Resource Limits and Supplier/Customer Disruptions. The implication is that Company D should concentrate on maintaining existing capabilities and improving new capabilities to anticipate and manage these issues. Emphasis on customer relationship management is critical to better manage the significant unpredictability in demand and its associated moderate scores of the frequency of customer disruptions.

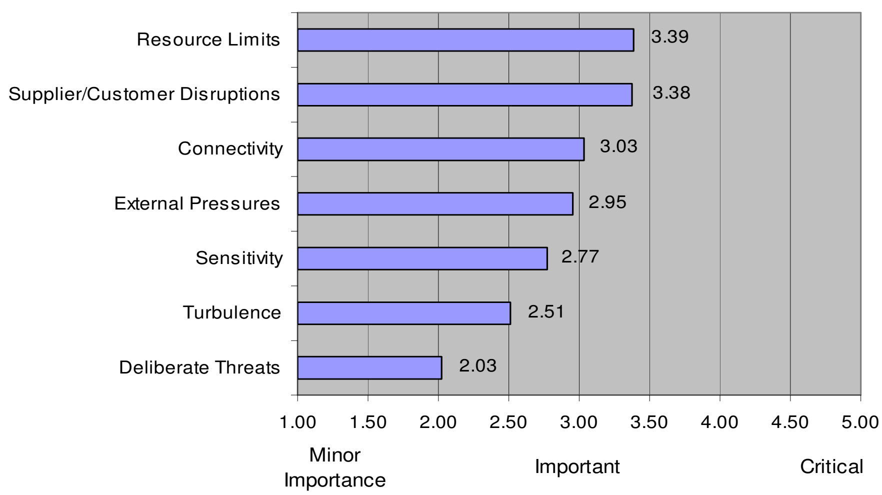

Figure D.7: Importance of Vulnerabilities

As vulnerabilities represent the fundamental factors that make an enterprise susceptible to disruptions, these factors are considered inherent in the enterprise's operating environment and therefore can not be affected in the short term. In the long term, strategic decisions altering the environment could radically change the supply chain, which would then require a re-evaluation. Therefore, the following section

provides tactical recommendations based on the capability scores, which represent the methods that an enterprise can utilize to anticipate and overcome disruptions.

Capability Results

In order to combat vulnerabilities, research has shown that a supply chain must have the capabilities needed to overcome its vulnerabilities for long-term survival. These supply chain capabilities create the ability to anticipate and potentially prevent a disruption, mitigate the effects of a disruption or adapt with new, more profitable processes, products or services. Table D.2 and Figure D.8 summarize the capability scores for Company D's self-assessment. Detailed sub-factor rankings are presented in Table D.4, listed at the end of this report.

Ranking	Capability	Factor Label	Average Score	Standard Deviation
1	Security	C13	4.07	0.45
2	Market Position	C12	3.99	0.45
3	Financial Strength	C14	3.90	0.56
4	Efficiency	C4	3.86	0.41
5	Recovery	C8	3.58	0.60
6	Organization	C11	3.55	0.62
7	Dispersion	C9	3.43	0.60
8	Anticipation	C7	3.41	0.64
9	Visibility	C5	3.28	0.82
10	Adaptability	C6	3.09	0.72
11	Flexibility in Sourcing	C1	2.93	0.52
12	Flexibility in Order Fulfillment	C2	2.91	0.67
13	Capacity	C3	2.91	0.89
14	Collaboration	C10	2.89	0.63

Table D.2: Capability Rankings

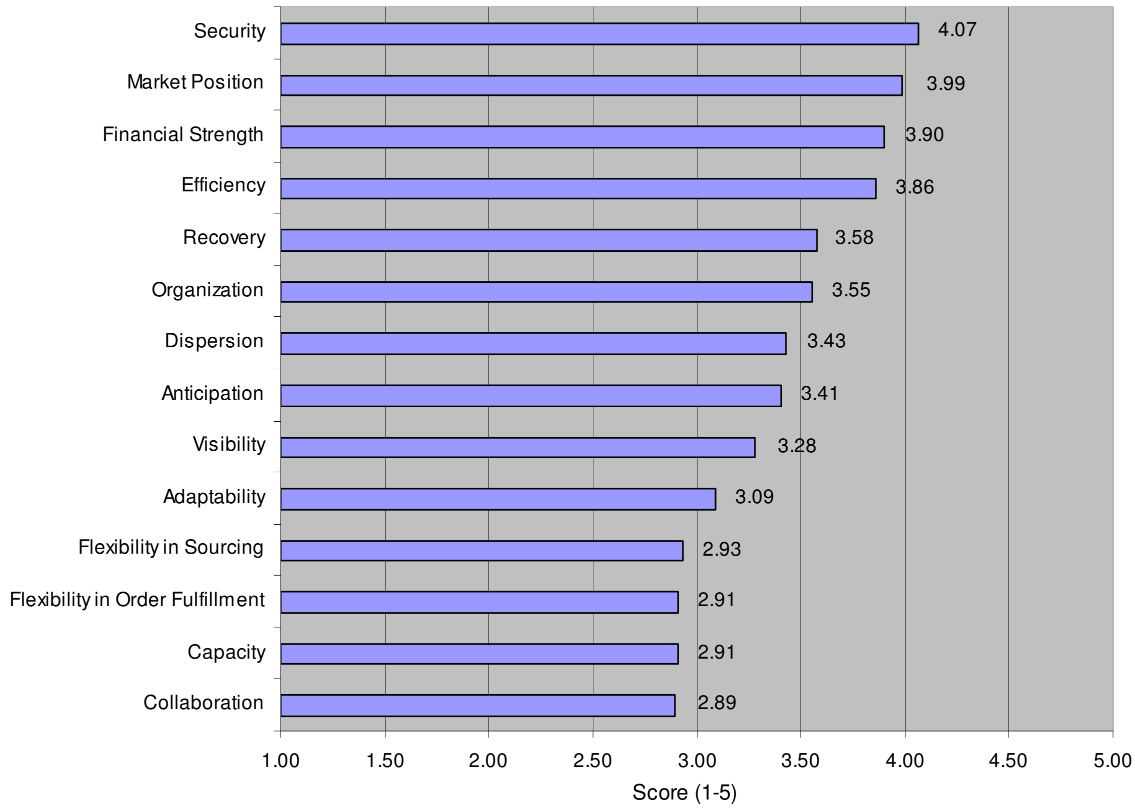

Figure D.8: Capability Scores

Company D's Resilience Team reported their strongest capability as Security. Sub-factors of Security are consistently high in all areas including strengths in cyber security, personnel security and access restrictions. One could argue that there is actually an over-expenditure on security, based on low scores for Deliberate Threats combined with the low level of importance placed on Deliberate Threats. Further studies of Supply Chain Resilience should investigate whether these low vulnerability scores are in fact an artifact of the successful Security programs in place at Company D.

Market Position, i.e., the status of the company and its products in specific markets, ranked as the second strongest capability. Scores were high in areas such as brand image and market share. These factors are critical in a competitive environment. Some improvement should be considered in the area of product differentiation, which will benefit future Market Position, and in conjunction with improved customer relationships will convey the benefits of high product margins as compared to competitors' offerings.

Financial Strength, i.e., the capacity to absorb fluctuations in cash flow, is ranked third, and is led by price margins. Additional strengths in this area are insurance coverage, financial reserves and portfolio diversification. The last of the top 4 capabilities is Efficiency, i.e., the capability to produce outputs with minimum resource requirements. The only area of concern in Efficiency is asset utilization, which, combined with low scores in Capacity, can be a sign of low production flexibility created from a lack of excess capacity or the presence of production bottlenecks that limit asset equalization throughout the production process.

On the opposite extreme, Company D's lowest capability scores are in Collaboration, Capacity, Flexibility in Order Fulfillment and Flexibility in Sourcing. First, Collaboration: the ability to work effectively with other entities for mutual benefit, should be a major area of concern in Company D's very Sensitive operations. The team scored postponement of orders as the second lowest of all 71 capability sub-factors. This is indicative of products critical to the customer's manufacturer process. Company D may consider forward locating more inventory, implementing Vendor Managed

Inventory (VMI) or working with customers to carry higher levels of their on-hand inventory. Collaborative information sharing, product life cycle management and risk sharing programs, currently among the lowest of capabilities, can then be enhanced to further improve inventory availability while reducing costs. In view of the significant vulnerability to Connectivity, these issues should be addressed immediately.

Another concern for Company D is Capacity: availability of assets to enable sustained production levels. However, with high-value production assets it may not be cost-effective to create excess capacity. Other capabilities such as Flexibility in Order Fulfillment and Anticipation may limit exposure to this risk.

Flexibility in Order Fulfillment, the ability to quickly change outputs or the mode of delivery outputs, has lowest scores in multiple sourcing. This capability combines organic production with outsourcing options to more cost-effectively meet peak demands. However, with very specialized products and limited alternative production, this may not be a feasible option for Company D. The second lowest rated element of Flexibility in Order Fulfillment is inventory management. This capability is critical to knowing "where" product inventory is located (in conjunction with Visibility systems) and computing "how much" to stock (in conjunction with Anticipation and Collaboration).

A final weakness is Flexibility in Sourcing, i.e., the ability to quickly change inputs or the mode of receiving inputs, which has its greatest weakness as alternative sourcing options. This may be a strategic decision made by Company D to centralize procurement; however, flexible terms and resilient suppliers are critical to make this effective. In addition, close relationships with key suppliers will be necessary, which are

not currently evident based on the low collaboration scores. Fortunately, supplies are used for common products and produced on common equipment which partially offsets the consolidation of suppliers. Company D should consider implementing the SCRAM™ tool or a similar screening protocol at key suppliers in order to better balance resilience throughout the tiers of the supply chain.

Analyzing the importance of the 14 Capability factors provides interesting insight into the relative priorities that should be placed on each area, see Figure D.9. Company D is most focused on Market Position and Capacity; however, this should not be overemphasized based on the expense of carrying excess Capacity if more flexible options are available. A serious concern is the low level of importance placed on Security, Visibility and Collaboration, especially Collaboration which has the lowest capability scores. Dispersion of high-value production assets appears to be of little concern due to the cost ramifications of dispersion; however, security should be critical to these high-value assets.

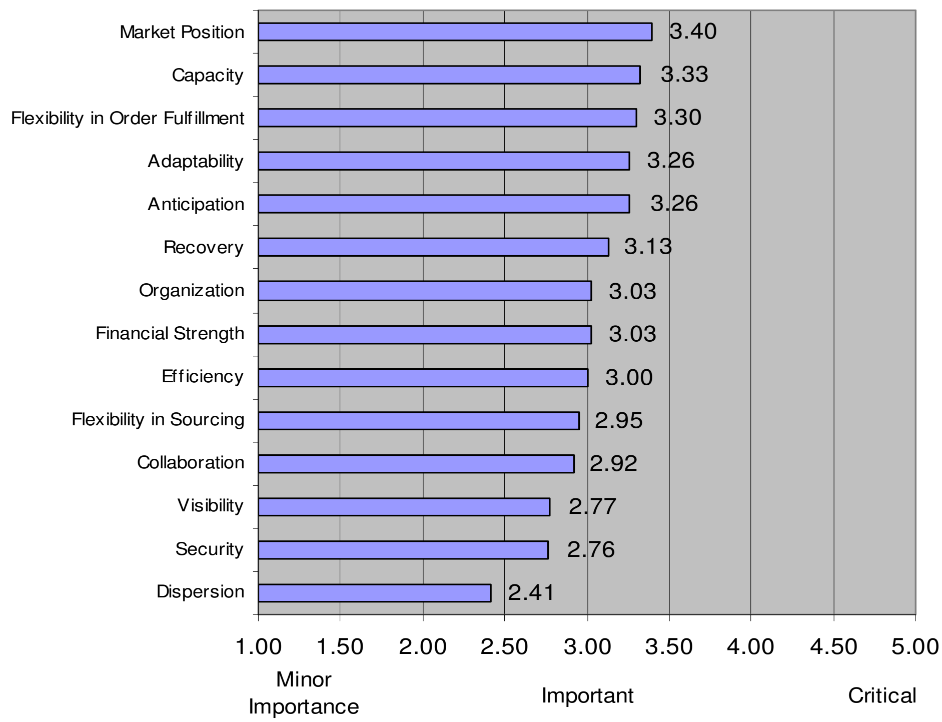

Figure D.9: Importance of Capabilities

Resilience Recommendations

Company D is commended for compiling an excellent Resilience Assessment Team. The team's composition matched well with the scope and goals determined by the project leaders. Through the team's investment of approximately 20 person-hours, a significant number of important issues were uncovered and discussed in this report. A summary follows:

- With highest threats from Connectivity, we recommend improving information exchange and collaborative information sharing (Planning and Production personnel rated demand forecasting much lower than other functions).

- Supplier disruptions were rated as more frequent than customer disruptions; we recommend a focus on selection of reliable suppliers and building greater resilience for key suppliers.
- Increase production Capacity in conjunction with Flexibility in Order Fulfillment and/or inventory of finished goods to combat very high levels of unpredictability in customer demand.
- Reduce lead-times, making recovery faster; rapid transportation combined with short production change-overs will benefit Flexibility in Order Fulfillment.
- Improve Anticipation and Collaborative Forecasting, which can be very cost-effective as compared to major, long-term investments in production Capacity.
- Security against physical and cyber threats is very strong; continue these Security efforts in light of the high reliance to information flow.
- External Pressures are well balanced with strengths in waste elimination, collaboration with government and high price margins, although we recommend considering improved business intelligence, production efficiency and technology development
- Explore the significant discrepancy in Business Intelligence scores between customer-facing functions (Marketing, Sales and Customer Service) and the operations-facing functions (Logistics and Management, with Production rating "Don't Know").
- Explore another discrepancy in technology development: Supply Chain Management and Process Improvement rated this area low, while all other functions gave strong scores.
- Consider improved Dispersion, although it may not be an option in this highly capital-intensive operation.
- Based on high threats related to Sensitivity issues, maintain strong Efficiency based on strict quality controls.

Follow-on studies at the Center for Resilience and the Fisher College of Business are currently being conducted to empirically validate various types of tactical recommendations, as well as benchmarking between firms to gain greater fidelity in the assessment tool. To assist in accomplishing this effort, historical demand and performance data covering the time-period of this study was collected at Company D.

Opportunities exist to continue collaboration in order to better define the successful capabilities that can be employed to overcome each specific vulnerability.

OSU has proposed “Phase II: Ensuring Supply Chain Resilience”, which will consist of small-group interviews to evaluate recent disruptions. Consolidating Company D’s data with data from other participating firms will culminate in a benchmarking report due in late summer 2008. These findings will further assist Company D in integrating resilience concepts into management improvement programs.

Ranking	Average	Label	Sub-factor	Factor
1	4.48	V5.8	Symbolic profile of brand	Sensitivity
2	4.26	V6.4	Reliance upon information flow	Connectivity
3	4.12	V1.1	Unpredictability in customer demand	Turbulence
4	4.00	V3.6	Environmental changes	External Pressures
5	3.97	V6.2	Import/export channels	Connectivity
6	3.96	V5.9	Concentration of capacity	Sensitivity
7	3.94	V3.3	Price pressures	External Pressures
8	3.74	V6.3	Reliance upon specialty sources	Connectivity
9	3.66	V3.1	Competitive innovation	External Pressures
10	3.61	V5.2	Importance of product purity	Sensitivity
11	3.50	V5.1	Utilization of restricted materials	Sensitivity
12	3.50	V6.5	Degree of Outsourcing	Connectivity
13	3.45	V3.2	Government regulations	External Pressures
14	3.45	V4.3	Distribution capacity	Resource Limits
15	3.44	V5.3	Fragility	Sensitivity
16	3.39	V4.2	Production capacity	Resource Limits
17	3.36	V5.7	Visibility of disruption to stakeholders	Sensitivity
18	3.25	V7.2	Customer disruptions	Supplier/Customer Disruptions
19	3.20	V4.4	Raw material availability	Resource Limits
20	3.19	V4.1	Supplier capacity	Resource Limits
21	3.07	V1.2	Fluctuations in currencies & prices	Turbulence
22	3.07	V5.4	Complexity of process operations	Sensitivity
23	3.04	V4.6	Human resources	Resource Limits
24	3.03	V2.6	Product liability	Deliberate Threats
25	2.79	V3.4	Corporate responsibility	External Pressures
26	2.75	V6.1	Scale and Extent of supply network	Connectivity
27	2.59	V2.5	Industrial espionage	Deliberate Threats
28	2.58	V5.6	Potential safety hazards	Sensitivity
29	2.58	V2.1	Terrorism & sabotage	Deliberate Threats
30	2.54	V7.1	Supplier disruptions	Supplier/Customer Disruptions
31	2.53	V3.5	Social/Cultural changes	External Pressures
32	2.52	V1.4	Exposure to natural disasters	Turbulence
33	2.48	V1.3	Exposure to geopolitical disruptions	Turbulence
34	2.48	V5.5	Reliability of equipment	Sensitivity
35	2.32	V1.6	Pandemic	Turbulence
36	2.32	V4.5	Utilities availability	Resource Limits
37	2.28	V1.5	Unforeseen technology failures	Turbulence
38	2.00	V2.3	Union activities	Deliberate Threats
39	1.62	V2.4	Special interest groups	Deliberate Threats
40	1.43	V2.2	Piracy & theft	Deliberate Threats

Table D.3: Vulnerabilities by Score Rank

Ranking	Average	Item	Sub-Factor	Factor
1	4.58	C9.5	Geographic dispersion of markets	Dispersion
2	4.29	C12.1	Brand equity	Market Position
3	4.19	C13.5	Cyber-security	Security
4	4.16	C13.6	Personnel security	Security
5	4.14	C4.3	Waste elimination	Efficiency
6	4.13	C12.3	Market share	Market Position
7	4.06	C14.4	Price margin	Financial Strength
8	4.05	C13.4	Collaboration with governments	Security
9	4.05	C4.4	Product/part variability reduction	Efficiency
10	4.05	C4.1	Labor productivity	Efficiency
11	4.00	C11.1	Creative problem solving culture	Organization
12	3.97	C12.2	Customer loyalty/retention	Market Position
13	3.97	C13.3	Employee involvement in security	Security
14	3.97	C13.2	Access restriction	Security
15	3.94	C13.1	Layered defenses	Security
16	3.94	C12.6	Communications	Market Position
17	3.90	C14.3	Insurance coverage	Financial Strength
18	3.86	C12.5	Relationships	Market Position
19	3.79	C3.1	Backup energy sources	Capacity
20	3.77	C14.1	Financial reserves & liquidity	Financial Strength
21	3.76	C14.2	Portfolio diversification	Financial Strength
22	3.75	C4.5	Failure prevention	Efficiency
23	3.74	C1.1	Common product platforms	Flexibility in Sourcing
24	3.73	C8.4	Consequence mitigation	Recovery
25	3.71	C12.4	Product differentiation	Market Position
26	3.70	C6.6	Learning from experience	Adaptability
27	3.66	C11.6	Culture of caring for employees	Organization
28	3.63	C5.1	Information technology	Visibility
29	3.58	C8.3	Crisis management	Recovery
30	3.57	C8.1	Resource mobilization	Recovery
31	3.55	C11.5	Benchmarking/ Feedback – Learning Organization	Organization
32	3.54	C6.4	Alternative technology development	Adaptability
33	3.54	C7.6	Recognition of opportunities	Anticipation
34	3.52	C7.3	Monitoring & Communicating deviations & near misses	Anticipation
35	3.52	C6.5	Lead time reduction	Adaptability
36	3.52	C11.3	Diversity of skills & experience	Organization
37	3.50	C9.4	Location-specific empowerment	Dispersion
38	3.48	C11.2	Accountability	Organization
39	3.46	C5.2	Products, Assets, People	Visibility
40	3.45	C7.2	Risk identification & prioritization	Anticipation

Continued

Table D.4: Capabilities by Score Rank

Table D.4 continued

Ranking	Average	Item	Sub-Factor	Factor
41	3.43	C7.1	Demand forecasting methods	Anticipation
42	3.39	C9.3	Distributed leadership	Dispersion
43	3.38	C10.1	Collaborative forecasting	Collaboration
44	3.33	C8.2	Communications strategy	Recovery
45	3.32	C7.4	Recognition of early warning signals	Anticipation
46	3.29	C2.3	Demand pooling	Flexibility in Order Fulfillment
47	3.23	C5.3	Information exchange	Visibility
48	3.22	C2.2	Delayed commitment/Production postponement	Flexibility in Order Fulfillment
49	3.16	C11.4	Substitute leadership capacity	Organization
50	3.00	C4.2	Asset utilization	Efficiency
51	2.96	C1.3	Multiple pathways & skills	Flexibility in Sourcing
52	2.95	C1.2	Product/service modularity	Flexibility in Sourcing
53	2.95	C3.2	Redundancy (Assets, labor)	Capacity
54	2.93	C9.2	Distributed capacity & assets	Dispersion
55	2.93	C2.5	Alternate distribution channels	Flexibility in Order Fulfillment
56	2.88	C7.5	Contingency planning/Preparedness	Anticipation
57	2.87	C10.2	Collaborative information sharing	Collaboration
58	2.87	C10.5	Risk sharing with partners	Collaboration
59	2.85	C10.4	Product life cycle management	Collaboration
60	2.85	C2.4	Inventory management	Flexibility in Order Fulfillment
61	2.85	C6.3	Seizing advantage from disruptions	Adaptability
62	2.75	C1.4	Supply contract flexibility	Flexibility in Sourcing
63	2.75	C5.4	Business intelligence gathering	Visibility
64	2.50	C2.1	Multi-sourcing (peak vs. base)	Flexibility in Order Fulfillment
65	2.43	C3.3	Reserve capacity (Materials, assets, labor)	Capacity
66	2.42	C6.2	Strategic gaming & simulation	Adaptability
67	2.40	C6.1	Fast re-routing of requirements	Adaptability
68	2.33	C1.5	Alternate suppliers/Outsourcing options	Flexibility in Sourcing
69	2.29	C2.6	Reallocation	Flexibility in Order Fulfillment
70	2.23	C10.3	Postponement of orders	Collaboration
71	2.20	C9.1	Decentralization of key resources	Dispersion

Disruption Overviews

Container and Transport Availability to Asia
Company D, Disruption #1
(D1 – Supply-side)

Recent capacity limitations in transpacific ocean freight limited Company D's ability to satisfy the contracted delivery date for a specialty chemical product. This disruption began as shipment bookings were made and, due to a recent change in selection of the production plant, proper origin/destination codes were not loaded in Company D's logistics systems.

As this problem was resolved, last-minute container loading was further delayed by a change to company policy implementing "Prior Content" restrictions on the ISO containers used to ship this product in order to ensure product integrity. Therefore, sensitivity of the product further exasperated the availability of ISO containers, requiring these leased containers to be returned empty from overseas customers rather than utilizing the shipper's pool containers.

And finally, due to limited vessel capacity, booking for ocean transport from the US West Coast to Asian markets has increased from 7-10 day lead-time a year ago to 30-45 days recently. The time spent solving the origin/destination coding and sourcing acceptable ISO containers, left Company D without the necessary lead-time to advance book the ocean freight.

Transition of Production to New Site
Company D, Disruption #2
(D2 – Production)

A major capital investment began over 5 years ago to modify an existing plant to take over production of a critical product from an aging, inefficient plant that had been built in the 1930s. The new plant was to be redesigned from a single-product, continuous process production flow to a two-product "semi-continuous" batch process production model. Significant engineering projects were conducted for the modification and to allow for product change-over without cross-contamination to either product.

Initial planning and contingency planning were conducted well in advance and, as construction forecasts slipped the production start date by 2-months, buffer inventories produced in advance by the old plant were thought to suffice. As first production runs yielded poor quality materials, cross-contamination of follow-on product and equipment problems, stockpiles were quickly depleting. Compounding the problem, demand for the second product greatly exceeded forecasts and management decided to further delay production of the original product that had much lower profit margins. While production output was delayed, end-of-year orders surged to almost 140 percent of average monthly demand further depleting stocks. Although the product is a minor expense for customers, it is critical to customers' operations and stock-outs would cause extremely costly shut-downs. Limited storage and distribution assets were contributing factors that limited the stockpiling of finished goods prior to shut-down of the existing facility. In addition, due to the age of the existing facility and its foreign-sourced equipment, Company D operated at significant risk as repair of the old

equipment was not possible and no other production capacity existed in-house until the new plant was in full operation. Finally, plans for the new facility did not incorporate sufficient excess capacity to meet major back-ordered demands that may have been incurred during the transition.

Multiple Changes in Delivery Date for Extremely Large Order
Company D, Disruption #3
(D3 – Demand-side)

A major customer in the Chemical industry placed a very large order to support the initial production run of a new plant. As the plant is engineered based on the chemical properties of Company D's product, this contract was placed 3 years prior to delivery, originally scheduled for early-2008.

Product to fill this order was manufactured and preparing to ship in February 2008; however, at the beginning of the month, Company D was informed that the customer would not be able to take delivery of the project for one year due to construction delays. Construction estimates from the customer were soon revised back to mid-2008. As this order consisted of 1/3 of the total annual production, storage of the product is costly and storage limitations caps further production. As a specialty product with few customers, alternate demand for this volume of product does not exist.

APPENDIX E

COMPANY E

Overview

Company E is a global manufacturer of personal care items including several well-known brands. Operations studied include only US production and sales. Brands are sold primarily through retailers in the General Merchandise, Drug Store and Grocery segments. Annual sales are approximately $500 million.

Assessment Results: Company E

Supply Chain Resilience Assessment and Management
SCRAM™ 1.1

March 27, 2008

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The Center for Resilience
and
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The Ohio State University

EXECUTIVE SUMMARY

This self-assessment was completed at Company E by a team of 24 individuals during the period of March 3 - 11, 2008.

In a world of turbulent change, resilience is a key competency, since even the most carefully designed supply chain is susceptible to unforeseen factors. Businesses must be prepared to cope with a continuous stream of challenges, ranging from human errors to technological failures to natural disasters.

The Center for Resilience and the Fisher College of Business at The Ohio State University (OSU) have developed a new resilience framework to help businesses deal with change: ***resilience*** is "the ability of an enterprise to survive, adapt and grow in the face of change and uncertainty." We created a tool for measuring resilience in a business enterprise – Supply Chain Resilience Assessment & Management (**SCRAM**™) – to assess supply chain resilience in terms of two major dimensions:

- **Vulnerabilities** – fundamental factors that make an enterprise susceptible to disruptions
- **Capabilities** – attributes that enable an enterprise to anticipate and overcome disruptions

We define the Zone of Balanced Resilience as a state of balance between vulnerabilities and capabilities, where firms will achieve both long term profitability and protection against disruptions.

This report includes detailed results of the assessment and recommendations. Significant recommendations are as follows:

- Company E'S strongest capabilities are Financial strength, Visibility and Market position. Specific areas of strengths are its globally dispersed markets, brand equity, common inputs and price margin.
- The highest vulnerability facing Company E is External Pressures. Dominated by threats from competitive innovations and price pressures, Company E should focus their response capabilities in areas such as Adaptation, Anticipation, Efficiency and Market Position.
- Also of high vulnerability, Connectivity is a significant threat. Reliance on information, degree of outsourcing and scale/extent of supply network are major sub-factors. Improve Collaboration and Flexibility while maintaining strong Recovery capabilities.
- Based on vulnerabilities to Turbulence in demand and Resource Limits of production capacity, priority should be directed at increased production Capacity and Anticipation.

Company E has taken an important first-step in exploring resilience. The Center for Resilience and the Fisher College of Business at The Ohio State University have agreed to conduct a more detailed Phase II follow-up with Company E. The deliverables of this activity will include an action plan for ensuring supply chain resilience.

Assessment Results

Company E

Goals and Scope

The goal of the project is to create a baseline understanding of Company E's current level of Supply Chain Resilience. Based on this understanding of resilience, it is possible to develop a portfolio of enterprise capabilities that match effectively with the supply chain's inherent pattern of vulnerabilities. The scope of the project covers operations for all branded products of Company E. Customers are only those companies or individuals that Company E sells to directly: wholesalers and retail chains. Suppliers are the set of first-tier organizations outside of Company E that provide raw materials, components, equipment and services.

Team Composition

The Company E Resilience Assessment Team was selected using a multi-level, cross-functional design. It included operational positions as well as senior management in order to provide coverage of both tactical and strategic issues. Additionally, the team included members from several functional specialties within the scope of the study to ensure coverage across the broad framework of supply chain resilience. A total of 24 participants comprised the Resilience Assessment Team, with their functional roles depicted in Figure E.1.

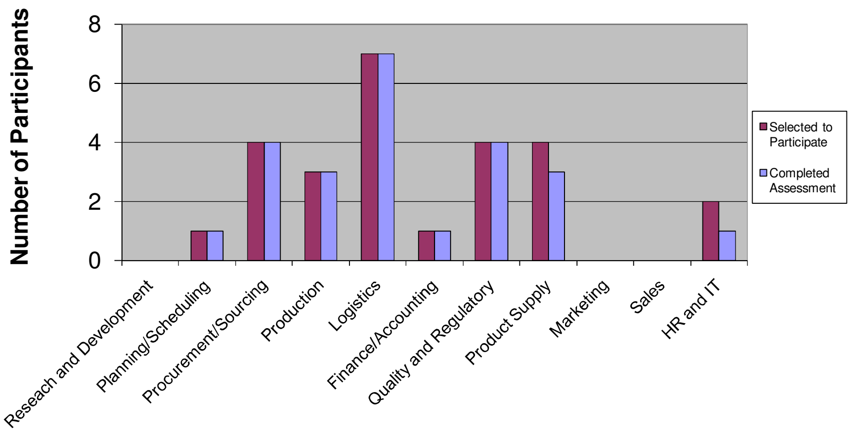

Figure E.1: Participants by Functional Area

Resilience Measurement

SCRAM™ 1.1: *Supply Chain Resilience Assessment and Management* assesses a firm's current *Portfolio of Capabilities* and facilitates matching of capabilities to the enterprise's *Pattern of Vulnerabilities*. Each team member completed a secure, on-line assessment during the period of March 3 - 11, 2008. The average amount of time to complete the survey was 27.5 minutes per person. During the assessment, team members responded to questions on a Likert Scale of 1 to 5, representing responses from "Strongly Disagree" to "Strongly Agree". Team members were allowed to select "Don't Know" or leave questions blank to prevent inexperienced responses from biasing the results. A minimal number of these responses were recorded (Don't Know = 9 percent, Blank = 1 percent), which is consistent with similar studies, and in general they matched appropriately against the respondent's job title and functional area (e.g. an inventory

clerk may not have detailed knowledge of corporate finances). Participants were generally consistent in responses even between functional areas.

Analysis of the data began at the strategic level. Responses for each item were averaged to form Factor Scores for each of the 7 Vulnerability factors and 14 Capability factors. An overall measure of resilience was then obtained by comparing the balance between the vulnerability and capability grand averages. Overall, Company E's resilience assessment results scored the consolidated capabilities at 3.41 (on a scale of 1 to 5) as compared to current vulnerabilities at 3.05. The assessment is graphically depicted in Figure E.2, with the composite score indicated. Individual scores show a relatively broad spread along both axes.

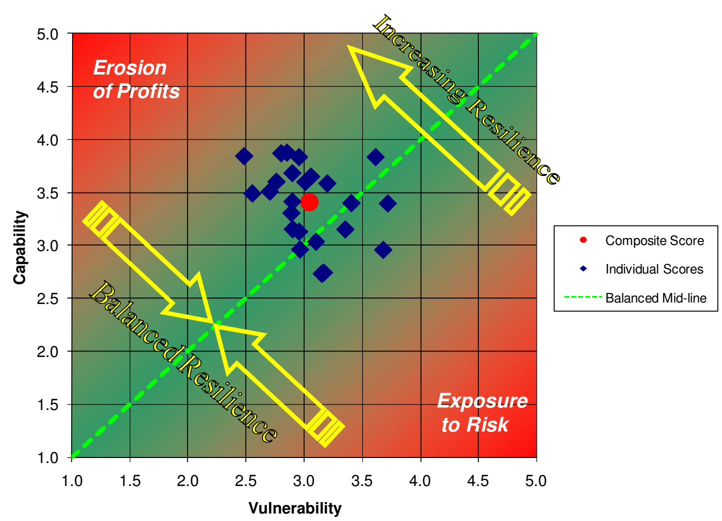

Figure E.2: Strategic Assessment Results

The following sections provide a review of vulnerability findings, capability findings and recommendations for capability improvements based on the current levels of vulnerabilities.

Vulnerability Results

The SCRAM™ assessment provides a clear distinction between high and low vulnerabilities. Overall, the responses are indicative of a global supply chain (high Connectivity) with very significant competition (high External Pressures). In addition, moderate levels of Resource Limits are noted. A summary of the scores and rankings are shown in Table E.1 and Figure E.3, while detailed sub-factor scoring is presented in Table E.3, listed at the end of this report.

Ranking	Vulnerability	Factor Label	Average Score	Standard Deviation
1	External Pressures	V3	3.96	0.54
2	Connectivity	V6	3.93	0.36
3	Resource Limits	V4	3.23	0.50
4	Sensitivity	V5	3.15	0.41
5	Turbulence	V1	2.53	0.63
6	Supplier/Customer Disruptions	V7	2.25	0.78
7	Deliberate Threats	V2	2.20	0.65

Table E.1: Vulnerability Rankings

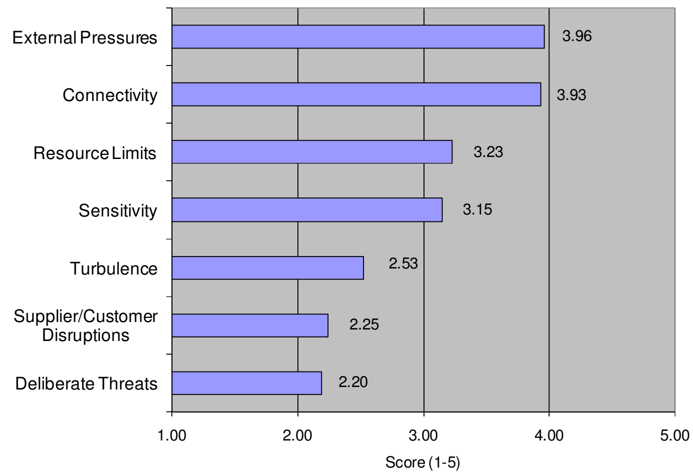

Figure E.3: Vulnerability Scores

External Pressures are strong vulnerabilities to Company E operations. Issues relating to competitive innovations, price pressures and government regulations all ranked in the top 10 of 40 vulnerability sub-factors. The remaining 3 sub-factors (corporate responsibility, environmental changes and social/culture changes) scored in the next 10. Efficiency programs can reduce costs in order to maintain price competitiveness – asset utilization scored in the Bottom 10 capabilities (#68 of 71 sub-factors). Also, an effective business intelligence program is critical to anticipate market shifts, regulatory changes and product innovations – this was rated as a moderate capability (#37 of 71).

Threats from competitive innovations also rank as a significant vulnerability, while Adaptability in alternative technology development is only moderate (3.41 of 5.00). Investments in product research and development and process improvements can combine to create a more flexible process to get new products to the market faster than

competitors. Government regulations are understandably a critical vulnerability to Company E's products and is slightly balanced with a moderate capability of collaboration with government regulators (3.35 of 5.00).

The team identified the second most vulnerable item as Connectivity: the degree of interdependence and reliance on outside entities. Four of the five sub-factors of connectivity rank in the Top 11 of 40 vulnerabilities sub-factors. The implication is that Company E should focus attention on Visibility and Collaboration capabilities such as improved data sharing and collaborative uses of shared information. A strong (negative) correlation exists between Collaboration and Connectivity, as team members consistently reported low Collaboration scores and high Connectivity scores (see Figure E.4).

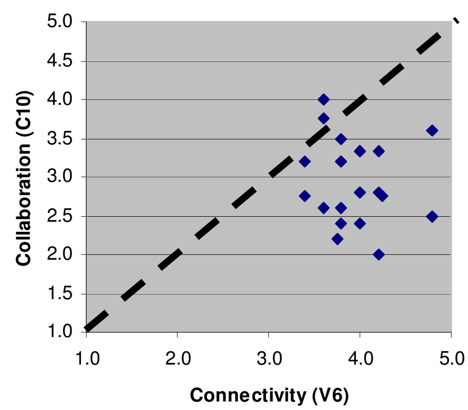

Figure E.4: Collaboration vs. Connectivity

The third-ranked vulnerability is Resource Limits, constraints on output based on availability of the factors of production. Production capacity is a significant vulnerability

in this category, scoring 4.13 of 5.00 and #6 of 40 overall. Discussions indicate that recent priority shifts towards increased production flexibility have created smaller batches thus forcing increased number of set-ups. This reduction in asset utilization appears to be impacting production capacity – process improvements to reduce “time per set-up” will allow for current levels of production flexibility and return need capacity. New capital investment in capacity may also be necessary based on future demand projections. Consider assets that can provide improvements in change-over speed to meet production flexibility goals as consistent with the need to overcome a moderate vulnerability to unpredictability in customer demand (3.63 of 5.00).

Supplier capacity is also a vulnerability of concern in the category of Resource Limits. Although current supplier disruptions are relatively low (2.42 of 5.00), there is a perception that suppliers can not meet current or future demands (3.86 of 5.00). Company E should consider evaluating the resilience of key suppliers, combined with partnership sessions directed on aligning supplier’s strategies, process and metrics with Company E. This will also contribute to increased trust between firms that will benefit collaborative programs such as risk/reward sharing and collaborative information exchanges.

The fourth-ranked vulnerability is Sensitivity, which means that Company E is dependent on carefully controlled conditions for product and process integrity. As expected, the symbolic profile of the brand and purity of products are high vulnerabilities. In such an environment, a firm must maintain strict quality control of processes and protect its facilities, especially where bottlenecks are present. Quality

management ranked as a strength, 3.91 of 5.00, and should continue to receive emphasis based on the vulnerability to Sensitivity.

Of note is the relatively low ranking of Turbulence, which is dominated by a single sub-factor of unpredictability in demand, with the five other sub-factors all rated "Neutral" or below. This poses the question of whether Company E's global markets face Turbulence more than reported, or if the capabilities created by the organization are successful in mitigating the effects of turbulent change. Current products have relatively long product life cycles, contributing to reduced Turbulence. In the future, however, competition and new production developments may change the threat from Turbulence and Company E should develop a corporate culture adaptable to change.

In regards to the unpredictability in demand, safety stock of materials can be a front-line defense to surges in demand. However, this buffer used as a single responsive capability can become extremely expensive based on Company E's product lines and dispersed markets. Therefore, Company E should consider a better balance of inventory with potentially less expensive options including minimal excess capacity and increased flexibility in distribution. Pooling of inventory can be very successful in mitigating unpredictability in localized demand if an agile distribution network is in place – currently rated strong at 3.73 of 5.00. Consider the long-term cost of stock outs in terms of sales, customer satisfaction and customer loyalty when investing in costly Recovery programs (ranked #4 of 14 capability factors). If brand loyalty is high (ranked #2 of 71 at 4.22 of 5.00), customers may be more willing to accepted delayed shipments or substitute products without significant reduction in long-term sales.

Following the assessment of each factor, each team member was asked to report their perception of the relative importance of each of the measures. These questions were reserved for the end of the assessment to ensure that respondents were exposed to each of the vulnerability and capability factors in order to better determine their relative priorities. Results of the relative importance of vulnerabilities are shown in Figure E.5. Two vulnerability factors stand out as most critical: Resource Limits and Supplier/Customer Disruptions. The implication is that Company E should concentrate on maintaining existing capabilities and improving new capabilities to anticipate and manage these issues. Emphasis on customer relationship management is critical to better manage the significant unpredictability in demand and its associated moderate scores of the frequency of customer disruptions.

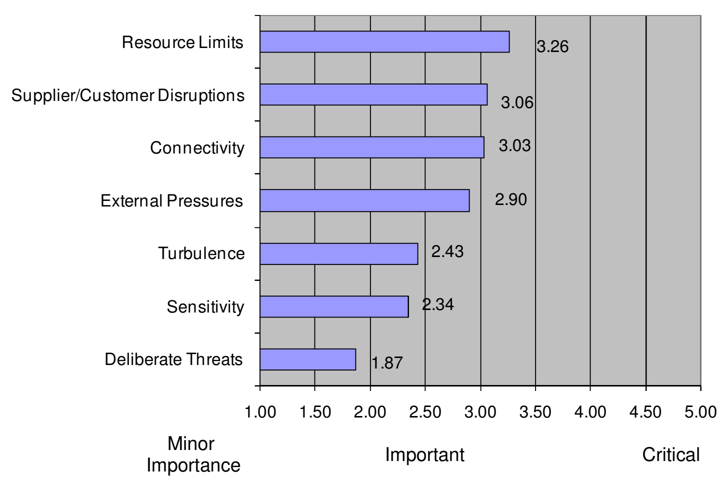

Figure E.5: Importance of Vulnerabilities

As vulnerabilities represent the fundamental factors that make an enterprise susceptible to disruptions, these factors are considered inherent in the enterprise's

operating environment and therefore can not be affected in the short term. In the long term, strategic decisions altering the environment could radically change the supply chain, which would then require a re-evaluation. The following section provides tactical recommendations based on the capability scores, which represent the methods that an enterprise can utilize to anticipate and overcome disruptions.

Capability Results

In order to combat vulnerabilities, research has shown that a supply chain must have the capabilities needed to overcome its vulnerabilities for long-term survival. These supply chain capabilities create the ability to anticipate and potentially prevent a disruption, mitigate the effects of a disruption or adapt with new, more profitable processes, products or services. Table E.2 and Figure E.6 summarize the capability scores for Company E's self-assessment. Detailed sub-factor rankings are presented in Table E.4, listed at the end of this report.

Ranking	Capability	Factor Label	Average Score	Standard Deviation
1	Financial Strength	C14	3.87	0.45
2	Visibility	C5	3.78	0.59
3	Market Position	C12	3.70	0.56
4	Recovery	C8	3.59	0.61
5	Efficiency	C4	3.57	0.38
6	Dispersion	C9	3.52	0.44
7	Flexibility in Order Fulfillment	C2	3.47	0.51
8	Flexibility in Sourcing	C1	3.37	0.44
9	Organization	C11	3.35	0.52
10	Security	C13	3.24	0.68
11	Adaptability	C6	3.17	0.55
12	Collaboration	C10	3.00	0.56
13	Anticipation	C7	3.00	0.64
14	Capacity	C3	2.99	0.83

Table E.2: Capability Rankings

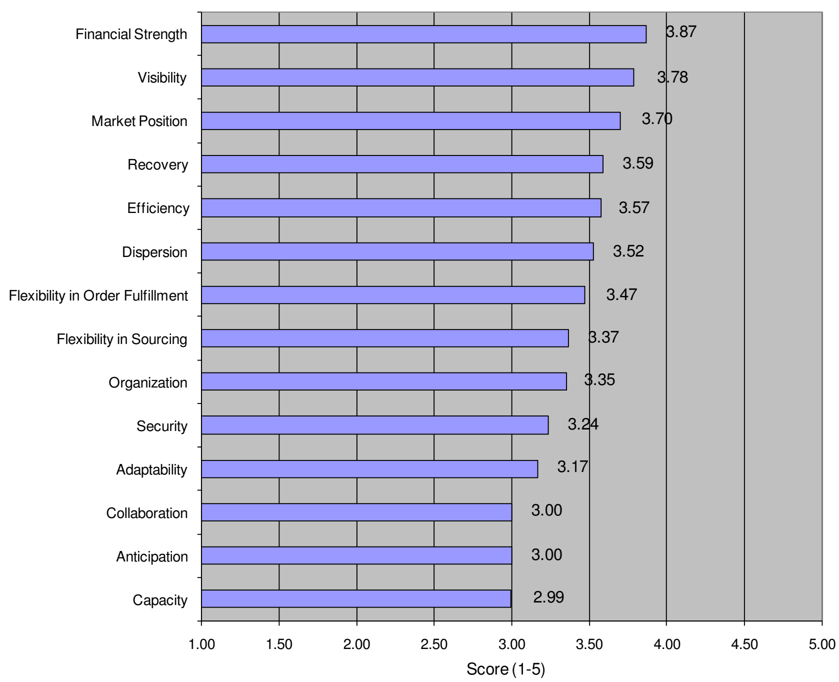

Figure E.6: Capability Scores

Company E's Resilience Team reported their strongest capability as Financial Strength, the capacity to absorb fluctuations in cash flow. This capability is led by price margins, which has been shown to be a significant asset in funding recovery efforts to maintain high customer satisfaction ratings. Marketing and R&D efforts to improve product differentiation (3.52 of 5.00) can also help to maintain high price margins. Additional strengths in this area are insurance coverage and financial reserves. Although insurance is important in the face of product liability vulnerabilities (3.42 of 5.00), the cost may be partially replaced through financial reserves (3.75 of 5.00) and process controls such as strict quality controls (3.91 of 5.00). Portfolio diversification was rated moderate (3.10 of 5.00) and may be improved to more successfully mitigate vulnerabilities to unpredictability in customer demand (#14 of 40) and competitive innovations (#1 of 40).

The second rated strength is Visibility, i.e. the knowledge of the status of operating assets and the environment. Company E is to be commended in this area as all other firms studied to date have been lacking in this area, despite advancement in Electronic Data Interchange (EDI). We also see Visibility as a precursor capability to other important capabilities such as Collaboration, Flexibility in Order Fulfillment, Anticipation and Recovery. All Visibility sub-factors were rated high, with the exception of moderate scores in business intelligence (3.41 of 5.00). Improvements in this area can benefit the ability to react to competitive innovations (#1 of 40) and market turbulence (#14 of 40).

The top 3 strengths are rounded out by Market Position, i.e., the status of the company and its products in specific markets. Scores were high in areas such as brand equity and customer communications. These factors are critical in a competitive environment. Although a strength, customer relationships (3.68 of 5.00) can still be improved, especially for key customers. This may also improve other areas such as collaborative forecasting (3.80 of 5.00) and postponement (3.13 of 5.00) and risk sharing (2.60 of 5.00). Improvement should be considered in the area of product differentiation (3.52 of 5.00), which will benefit future Market Position, and in conjunction with improved customer relationships will convey the benefits as compared to competitors' offerings, also contributing to maintaining high price margins.

On the opposite extreme, Company E's lowest capability score is Capacity: availability of assets to enable sustained production levels. However, with high-value production assets it may not be cost-effective to create large amounts excess capacity. Inventory of finished goods can buffer production from demand, although at the expense of inventory carrying costs. Other capabilities such as Flexibility in Order Fulfillment and Anticipation may limit exposure to this risk at lower costs.

Anticipation, the ability to discern potential future events or situations, is also a weakness of Company E (#13 of 14). Consider an improved process for contingency planning and exercising (2.30 of 5.00). With very small investments, these exercises can not only improve recovery efforts, but also day-to-day operations. Merging customers and suppliers into contingency planning and exercising can greatly improve the outcomes. Linking these efforts with an active business intelligence program can provide

insight into new processes or product variations. Risk identification and prioritization (2.75 of 5.00) was rated low, and as discussion highlighted, Company E can significantly improve the prioritization process. As it is cost-prohibitive to protect against all potential threats, building resilience into the Supply Chain can greatly improve an enterprises ability to manage change.

A weakness in Company E's Adaptability, the ability to modify operations in response to challenges or opportunities, is a lack of strategic gaming and simulation (1.86 of 5.00 and #71 of 71 capability sub-factors). This can be a very cost-effective tool to aid in decision making, especial when planning for high capital investments in production capacity and supply chain network redesign. Gaming with senior leaders can also improve empowerment through trust building activities and may even identify way to improve day-to-day operational efficiencies.

And finally, Collaboration: the ability to work effectively with other entities for mutual benefit, should be a major area of concern. The team scored risk sharing with partners lowest in this category (2.60 of 5.00 and #63 of 71). Partnership sessions will help to identify areas where risks and rewards can be shared while building trust in the relationships. Although collaborative forecasting is high (3.80 of 5.00), the information exchange is rated low (2.67 of 5.00). This may be a signal of partners using individual (not shared) data sources or manual interventions that may corrupt the common data-sets. Again, building trust with key partners will benefit the ability to transparently share data and then use the data in collaborative decision making. Also low scoring is customer willingness to postpone orders (2.70 of 5.00). Company E may consider implementing

Vendor Managed Inventory (VMI) to better manage inventory allocation decisions. In view of the significant vulnerability to Connectivity, these issues should be addressed immediately.

Analyzing the importance of the 14 Capability factors provides interesting insight into the relative priorities that should be placed on each area, see Figure E.7. Company E is most focused on Financial Strength and Market Position. A serious concern is the low level of importance placed on Dispersion, potentially an artifact of successful Dispersion of production assets (3.52 of 5.00) and a flexible distribution network (3.47 of 5.00). Little other analysis is possible due to the limited variation in responses.

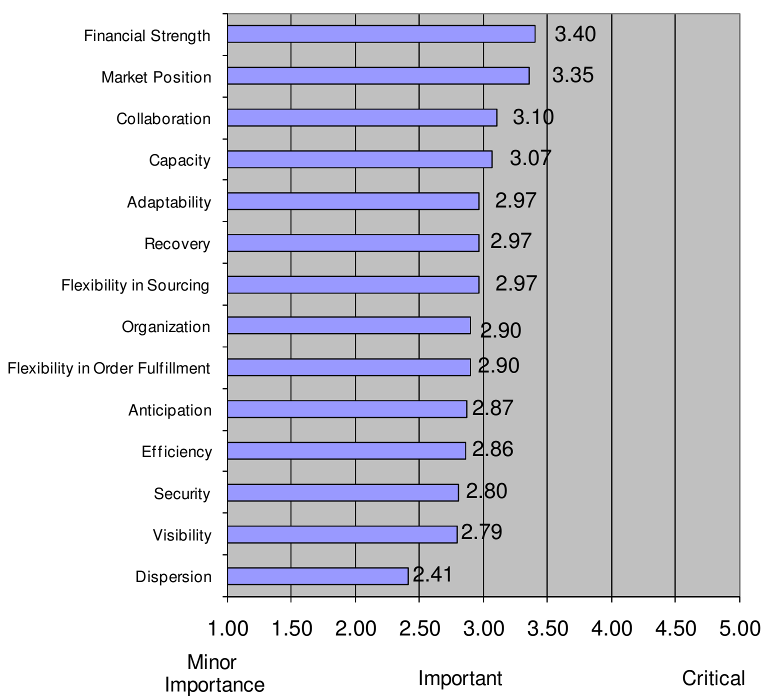

Figure E.7: Importance of Capabilities

Resilience Recommendations

Company E is commended for compiling an excellent Resilience Assessment Team. The team's composition matched well with the scope and goals determined by the project leaders. Through the team's investment of approximately 12 person-hours, a significant number of important issues were uncovered and discussed in this report. A summary follows:

- High vulnerability to unpredictable demand suggests increased Flexibility in Order Fulfillment, reduced Lead-times, improved Contingency planning and exercising and increased production Capacity.
- Product liability is high in the personal care market – maintain strict quality control programs and security of assets in the inbound, production and outbound channels.
- Anticipation and Adaptability should be improved to combat threats from Competitive innovations. Increased business intelligence programs can also be a more proactive response.
- To off-set strong price pressures in the market, process improvements can be addressed to increase production Efficiency, especially in the area of more rapid product change-overs and set-up times. Increasing asset utilization will also return some lost Capacity to meet surge demands.
- Production and Supplier capacity are concerns. Ensure that internal capacity is matched with supplier capacity, both in their production assets and in the distribution network. Consider partnership session with key suppliers to align processes to more accurately connect forecasts to capacity.
- Protect the strong brand image and price margins through strict quality controls, both in the production facilities and with supplier inputs. Ensure distribution networks have similar handling and storage controls.
- Improve technology development programs to maintain product differentiation in view of threats from competitive innovations. Price margins can quickly erode without product differentiation.
- Leverage the reliability of suppliers; consider postponement of production wherever technically feasible and the distribution network is agile enough. This will reduce the forecasting time horizon to improve Anticipation programs.

- Strategic Gaming and Simulation can be a very cost-effective methodology for decision making and will improve Adaptability, especially when considering alternatives between capabilities -- i.e. Capacity vs. Flexibility.

Follow-on studies at the Center for Resilience and the Fisher College of Business are currently being conducted to empirically validate various types of tactical recommendations, as well as benchmarking between firms to gain greater fidelity in the assessment tool. To assist in accomplishing this effort, historical demand and performance data covering the time-period of this study will be collected from Company E. Opportunities exist to continue collaboration with The Ohio State University in order to better define the successful capabilities that can be employed to overcome each specific vulnerability.

To achieve this goal, OSU has proposed “Phase II: Ensuring Supply Chain Resilience”, which will consist of small-group interviews to evaluate recent disruptions. Consolidating Company E’s interview data with data from other participating firms will culminate in a benchmarking report due in late summer 2008. These findings will further assist Company E in integrating resilience concepts into management improvement programs.

Ranking	Average	Label	Sub-factor	Factor
1	4.67	V3.1	Competitive innovation	External Pressures
2	4.63	V3.3	Price pressures	External Pressures
3	4.58	V5.8	Symbolic profile of brand	Sensitivity
4	4.29	V6.4	Reliance upon information flow	Connectivity
5	4.23	V5.2	Importance of product purity	Sensitivity
6	4.13	V4.2	Production capacity	Resource Limits
7	4.13	V6.5	Degree of Outsourcing	Connectivity
8	4.00	V6.2	Import/export channels	Connectivity
9	3.86	V4.1	Supplier capacity	Resource Limits
10	3.83	V3.2	Government regulations	External Pressures
11	3.73	V6.1	Scale and Extent of supply network	Connectivity
12	3.71	V3.4	Corporate responsibility	External Pressures
13	3.64	V3.6	Environmental changes	External Pressures
14	3.63	V1.1	Unpredictability in customer demand	Turbulence
15	3.45	V6.3	Reliance upon specialty sources	Connectivity
16	3.42	V2.6	Product liability	Deliberate Threats
17	3.26	V3.5	Social/Cultural changes	External Pressures
18	3.20	V5.1	Utilization of restricted materials	Sensitivity
19	3.15	V4.4	Raw material availability	Resource Limits
20	3.13	V4.6	Human resources	Resource Limits
21	3.10	V5.9	Concentration of capacity	Sensitivity
22	3.04	V5.3	Fragility	Sensitivity
23	2.90	V5.4	Complexity of process operations	Sensitivity
24	2.84	V1.2	Fluctuations in currencies & prices	Turbulence
25	2.82	V5.7	Visibility of disruption to stakeholders	Sensitivity
26	2.65	V5.5	Reliability of equipment	Sensitivity
27	2.61	V1.6	Pandemic	Turbulence
28	2.55	V4.3	Distribution capacity	Resource Limits
29	2.42	V7.1	Supplier disruptions	Supplier/Customer Disruptions
30	2.42	V2.5	Industrial espionage	Deliberate Threats
31	2.29	V2.1	Terrorism & sabotage	Deliberate Threats
32	2.11	V4.5	Utilities availability	Resource Limits
33	2.10	V1.3	Exposure to geopolitical disruptions	Turbulence
34	2.08	V2.2	Piracy & theft	Deliberate Threats
35	2.05	V7.2	Customer disruptions	Supplier/Customer Disruptions
36	2.04	V1.5	Unforeseen technology failures	Turbulence
37	2.00	V1.4	Exposure to natural disasters	Turbulence
38	1.63	V5.6	Potential safety hazards	Sensitivity
39	1.45	V2.4	Special interest groups	Deliberate Threats
40	1.35	V2.3	Union activities	Deliberate Threats

Table E.3: Vulnerabilities by Score Rank

Ranking	Average	Item	Sub-Factor	Factor
1	4.35	C9.5	Geographic dispersion of markets	Dispersion
2	4.22	C12.1	Brand equity	Market Position
3	4.17	C1.1	Common product platforms	Flexibility in Sourcing
4	4.17	C14.4	Price margin	Financial Strength
5	4.06	C2.5	Alternate distribution channels	Flexibility in Order Fulfillment
6	4.05	C4.1	Labor productivity	Efficiency
7	4.04	C11.1	Creative problem solving culture	Organization
8	4.00	C4.5	Failure prevention	Efficiency
9	3.96	C8.1	Resource mobilization	Recovery
10	3.93	C14.3	Insurance coverage	Financial Strength
11	3.91	C4.3	Quality management	Efficiency
12	3.91	C5.3	Information exchange	Visibility
13	3.88	C3.1	Backup energy sources/communications	Capacity
14	3.88	C9.2	Distributed capacity & assets	Dispersion
15	3.86	C8.4	Consequence mitigation	Recovery
16	3.83	C12.6	Communications	Market Position
17	3.83	C5.1	Information technology	Visibility
18	3.83	C6.5	Lead time reduction	Adaptability
19	3.80	C10.1	Collaborative forecasting	Collaboration
20	3.78	C5.2	Products, Assets, People	Visibility
21	3.78	C13.5	Cyber-security	Security
22	3.77	C2.1	Multi-sourcing (peak vs. base)	Flexibility in Order Fulfillment
23	3.75	C14.1	Financial reserves & liquidity	Financial Strength
24	3.73	C1.4	Supply contract flexibility	Flexibility in Sourcing
25	3.73	C2.3	Demand pooling	Flexibility in Order Fulfillment
26	3.68	C4.4	Preventative maintenance	Efficiency
27	3.68	C12.5	Relationships	Market Position
28	3.67	C9.4	Location-specific empowerment	Dispersion
29	3.61	C1.3	Multiple pathways & skills	Flexibility in Sourcing
30	3.61	C6.6	Learning from experience	Adaptability
31	3.57	C11.5	Benchmarking/ Feedback – Learning Organization	Organization
32	3.52	C11.6	Culture of caring for employees	Organization
33	3.52	C12.2	Customer loyalty/retention	Market Position
34	3.52	C12.3	Market share	Market Position
35	3.52	C12.4	Product differentiation	Market Position
36	3.42	C2.4	Inventory management	Flexibility in Order Fulfillment
37	3.41	C5.4	Business intelligence gathering	Visibility

Continued

Table E.4: Capabilities by Score Rank

Table E.4 continued

Ranking	Average	Item	Sub-Factor	Factor
38	3.41	C6.4	Alternative technology development	Adaptability
39	3.41	C7.1	Demand forecasting methods	Anticipation
40	3.35	C13.4	Collaboration with governments	Security
41	3.32	C8.3	Crisis management	Recovery
42	3.17	C7.3	Monitoring & Communicating deviations & near misses	Anticipation
43	3.17	C13.2	Access restriction	Security
44	3.17	C13.3	Employee involvement in security	Security
45	3.15	C9.1	Decentralization of key resources	Dispersion
46	3.14	C6.3	Seizing advantage from disruptions	Adaptability
47	3.14	C8.2	Communications strategy	Recovery
48	3.14	C10.4	Product life cycle management	Collaboration
49	3.13	C2.2	Delayed commitment/Production postponement	Flexibility in Order Fulfillment
50	3.10	C14.2	Portfolio diversification	Financial Strength
51	3.09	C7.4	Recognition of early warning signals	Anticipation
52	3.04	C11.3	Diversity of skills & experience	Organization
53	3.00	C7.6	Recognition of opportunities	Anticipation
54	3.00	C11.2	Accountability	Organization
55	3.00	C13.6	Personnel security	Security
56	2.94	C1.2	Product/service modularity	Flexibility in Sourcing
57	2.91	C11.4	Substitute leadership capacity	Organization
58	2.82	C13.1	Layered defenses	Security
59	2.75	C7.2	Risk identification & prioritization	Anticipation
60	2.73	C3.2	Redundancy (Assets, labor)	Capacity
61	2.70	C10.3	Postponement of orders	Collaboration
62	2.67	C10.2	Collaborative information sharing	Collaboration
63	2.60	C10.5	Risk sharing with partners	Collaboration
64	2.59	C3.3	Reserve capacity	Capacity
65	2.50	C2.6	Reallocation	Flexibility in Order Fulfillment
66	2.50	C9.3	Distributed leadership	Dispersion
67	2.48	C6.1	Fast re-routing of requirements	Adaptability
68	2.39	C4.2	Asset utilization	Efficiency
69	2.30	C7.5	Contingency planning/Preparedness	Anticipation
70	2.21	C1.5	Alternate suppliers/Outsourcing options	Flexibility in Sourcing
71	1.86	C6.2	Strategic gaming & simulation	Adaptability

Disruption Overviews

Instability of Product Formulation from Supplier
Company E, Disruption #1
(E1 - Supply-side)

Initial product launch from 2005 received negative customer comments noting a mild odor of the product. The addition of a mild fragrance and other minor formulation changes were developed and tested. Standard policies were followed, which included pilot production runs in the company's test facility. All product specifications were met. Analysis of product at manufacture passed quality tests, including product stability testing after 1-month and 3-months. Transition of new formulation to the production facility in February 2007 went well, with product again passing all required tests, although a slight change in pH was noted. However, after the new product was began selling during late summer 2007, customer complaints began coming in on the company's toll-free comment line. Customers were displeased with the "thin" product (low viscosity) and because of this questioned the effectiveness of the product. Internal testing of the product confirmed the change in viscosity from design parameters and from the analyses conducted at 3-months shelf-life. Although no health issues were found and a product recall was not initiated, the product did not meet customer expectations and all on-hand stocks were frozen for future shipment.

After further review, Company E decided to dispose of all on-hand stock valued at $2.5 million, at a disposal cost of $41,000. In addition, recovery efforts to fill an existing formulation into available bottles proved difficult for trial-size tubes as over-labeling was required for all SKUs to show the current ingredients. Additional testing of

adhesives for the over-labeling for the trial-size tubes was conducted further delaying shipments to customers. An additional $500,000 in re-labeling expenses was incurred, with stock level goals not met for 3 weeks for standard bottles and almost 4 months for trial sizes.

Note: Company E elected to not study a production disruption (Case Study #2) as this supply disruption included production aspects as well.

Major Demand Changes for Promotional Item
Company E, Disruption #3
(E3 - Demand-side)

A major retail customer of Company E was initially expected to deploy a new trial-size of an existing product into 100 stores based on a new floor-set for Travel/Trial display. Less than 1 month prior to planned deliveries, the customer communicated that the display would be launched in 1,767 stores, not the originally planned 100 stores. Initial orders came in for 2,694 cases, yet only 1,388 cases were scheduled to be produced from the original order and other customer orders.

Due to product shortage, orders to all other customers were cancelled and product was allocated to only the top 1,000 stores of the major retailer. Stores receiving product received only 1 or 2 cases based on store size, instead of the 10 cases originally ordered. Stock levels averaged 55 percent during the launch of the new Travel/Trial displays, until additional production was shipped 3 months later. Final stock goals were not met for another month.

APPENDIX F

COMPANY F

Overview

Company F is an LLC of a global manufacturing firm in the building materials industry. Company F specializes in producing world-class materials for both residential and commercial construction. Overall corporate revenues are approximately $5 billion annually.

Note: Company F requested that their SCRAM^{TM} assessment not be published herein.

APPENDIX G

COMPANY G

Overview

Company G is a division of a multinational chemical company headquartered in the United States. This division is a newly created "market facing" organization designed to provide each customer with their complete range of specialty products. To create a more cross-functional sample in line with the research methodology, a major Tier 1 supplier within the same corporation was added to the sample to ensure inclusion of functions such as procurement and manufacturing. These groups were analyzed separately and together to provide greater fidelity to the management of these new entities.

Supply Chain Resilience Assessment and Management
SCRAM^{TM} 1.1

of

Company G

June 10, 2008

prepared by:

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from the

The Center for Resilience
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Fisher College of Business
The Ohio State University

EXECUTIVE SUMMARY

This report is based on a self-assessment exercise that was completed at Company G, by a team of 36 individuals, during the period from April 29 to March 13, 2008.

In a world of turbulent change, resilience is a key competency, since even the most carefully designed supply chain is susceptible to unforeseen factors. Businesses must be prepared to cope with a continuous stream of challenges, ranging from human errors to technological failures to natural disasters.

The Center for Resilience and the Fisher College of Business at The Ohio State University (OSU) have developed a new resilience framework to help businesses deal with change: ***resilience*** is "the ability of an enterprise to survive, adapt and grow in the face of change and uncertainty." We created a tool for measuring resilience in a business enterprise – Supply Chain Resilience Assessment & Management (**SCRAM**™) – by assessing supply chain resilience in terms of two major dimensions:

- **Vulnerabilities** – fundamental factors that make an enterprise susceptible to disruptions
- **Capabilities** – attributes that enable an enterprise to anticipate and overcome disruptions

We define the Zone of Balanced Resilience as a state of balance between vulnerabilities and capabilities, where firms will achieve both long term profitability and protection against disruptions.

This report includes detailed results of the self-assessment, as well as analysis and recommendations. Significant recommendations are as follows:

- Company G's strongest areas of capability are Security, Dispersion and Organization. Specific strengths include a dispersion of markets, commonality of inputs and personal/cyber-security.
- The area of greatest vulnerability facing Company G is Connectivity, followed by External Pressures and Sensitivity. Many Connectivity threats may be addressed through effective Visibility and Collaboration capabilities.
- However, Collaboration appears to be an area of relative weakness given Company G's broad supply base and geographically dispersed markets. Company G should collaborate with customers to better match deliveries with must-meet dates. In addition, programs should be considered to include customers and suppliers in product life cycle management and risk sharing activities.
- Capacity, Flexibility in Sourcing, Flexibility in Order Fulfillment and Adaptability are also areas of relative weakness and may represent factors inherent in a process manufacturing industry. With very high-value assets, it may be more cost-effective

to increase Flexibility in Order Fulfillment than to maintain excess production Capacity.

Company G has taken an important first-step in exploring resilience. The Ohio State University team has agreed to conduct a more detailed Phase II follow-up with Company G. The deliverables of this activity will include an action plan for ensuring supply chain resilience.

Assessment Results

Company G

Goals and Scope

The goal of the project is to create a baseline understanding of Company G's current level of Supply Chain Resilience. Based on these resilience scores, it is possible to develop enterprise capabilities that match effectively with the supply chain's inherent vulnerabilities. The scope of the project covers operations of Company G's Market Facing organization. A companion study was also conducted with an internal Tier 1 supplier as the production organization to Company G – not included in this report. Customers are only those companies or individuals that Company G sells to directly, typically *not* the end consumer. Suppliers are the set of first-tier organizations outside of Company G that provide raw materials, components, equipment and services, including those units within Company G.

Team Composition

The Company G Resilience Assessment Team was selected using a multi-level, cross-functional design. It included operational positions as well as senior management in order to provide coverage of both tactical and strategic issues. Additionally, the team included members from several functional specialties within the scope of the study to ensure coverage across the broad framework of supply chain resilience. A total of 36

participants comprised the Resilience Assessment Team, with their functional roles depicted in Figure G.1.

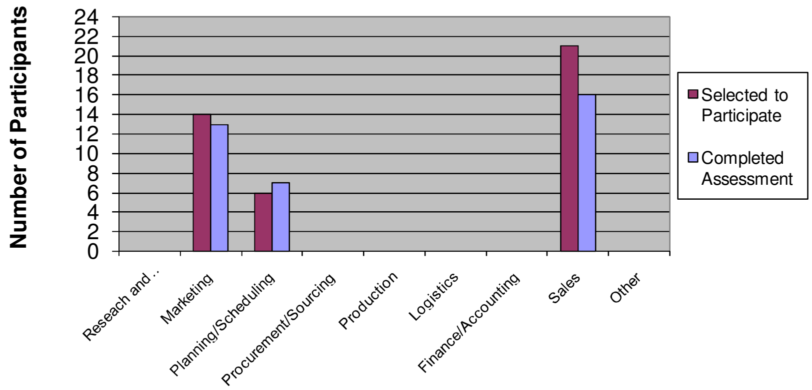

Figure G.1: Participants by Functional Area

Resilience Measurement

SCRAM™ 1.1: *Supply Chain Resilience Assessment and Management* assesses a firm's current ***Portfolio of Capabilities*** and facilitates matching of capabilities to the enterprise's ***Pattern of Vulnerabilities***. Each team member completed a secure, on-line assessment during the period from April 29 to March 13, 2008. The average amount of time to complete the survey was 29.2 minutes per person. During the assessment, team members responded to questions on a Likert Scale of 1 to 5, representing responses from "Strongly Disagree" to "Strongly Agree". Team members were allowed to select "Don't Know" or leave questions blank to prevent inexperienced responses from biasing the results. A minimal number of these responses were recorded (Don't Know = 10 percent, Blank = 1 percent), which is consistent with similar studies, and in general they matched

appropriately against the respondent's job title and functional area (e.g. an inventory clerk may not have detailed knowledge of corporate finances). Participants were generally consistent in responses even between functional areas.

Analysis of the data began at the strategic level. Responses for each item were averaged to form Factor Scores for each of the 7 Vulnerability factors and 14 Capability factors. An overall measure of resilience was then obtained by comparing the balance between the vulnerability and capability grand averages. Overall, Company G's resilience assessment results scored the consolidated capabilities at 3.40 (on a scale of 1 to 5) as compared to current vulnerabilities at 3.32. The assessment is graphically depicted in Figure G.2, with the composite score indicated. Individual scores show a relatively minor spread along both axes.

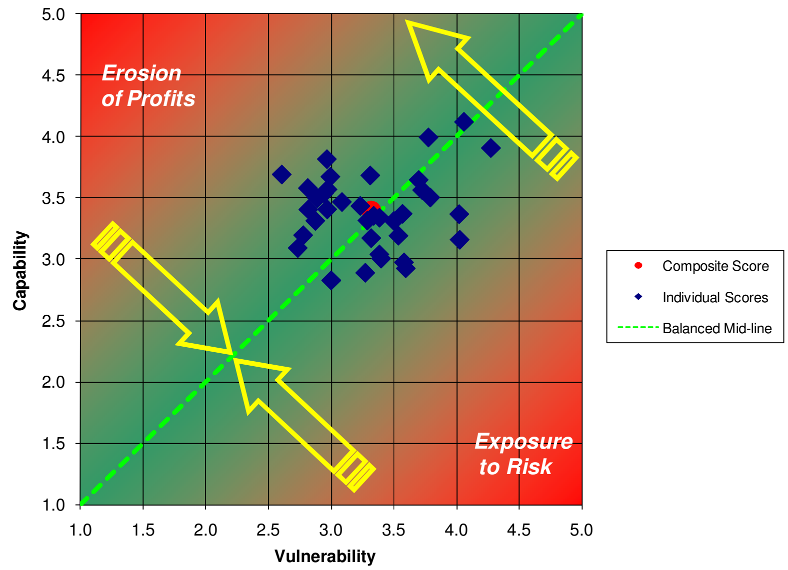

Figure G.2: Strategic Assessment Results

The following sections provide a review of vulnerability findings, capability findings and recommendations for capability improvements based on the current levels of vulnerabilities.

Vulnerability Results

The SCRAM™ assessment provides a clear distinction between high and low vulnerabilities. Overall, the responses are indicative of a global supply chain (high Connectivity) with very sensitive products and processes (high Sensitivity). In addition, high levels of External Pressures are noted in the areas of price pressures, environmental issues, governmental regulations and competitive innovation. A summary of the scores and rankings are shown in Table G.1 and Figure G.3, while detailed sub-factor scoring is presented at the end of this report.

Ranking	Vulnerability	Factor Label	Average Score	Standard Deviation
1	Connectivity	V6	3.93	0.55
2	External Pressures	V3	3.83	0.61
3	Sensitivity	V5	3.68	0.46
4	Resource Limits	V4	3.47	0.60
5	Supplier/Customer Disruptions	V7	3.13	0.97
6	Turbulence	V1	2.69	0.65
7	Deliberate Threats	V2	2.49	0.70

Table G.1: Vulnerability Rankings

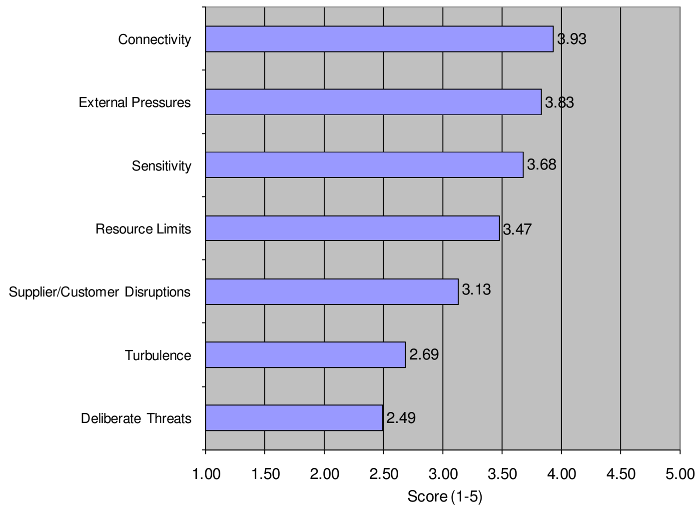

Figure G.3: Vulnerability Scores

The team identified the overall most vulnerable item as Connectivity: the degree of interdependence and reliance on outside entities. Two of the top 10 sub-factors are Connectivity issues, which are reliance on information flow and extent of import/export channels. The implication is that Company G should focus attention on Visibility and Collaboration capabilities such as improved data sharing and collaborative uses of shared information. A strong (negative) correlation exists between Collaboration and Connectivity, as team members consistently reported low Collaboration scores and high Connectivity scores (see Figure G.4). The major contributor of this trend is several very low Collaborative Information Sharing ratings and very consistent high ratings for Reliance upon Information Flow (see Figure G.5).

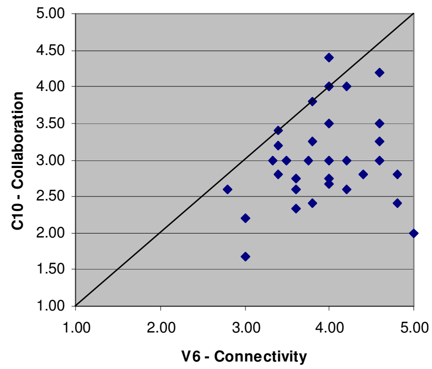

Figure G.4: Collaboration vs. Connectivity

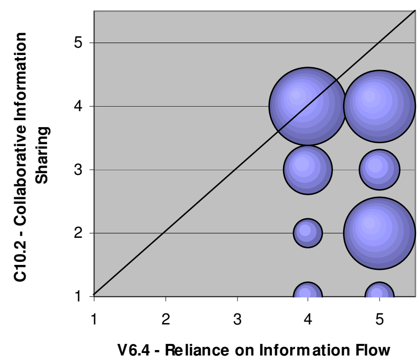

Figure G.5: Collaborative Info Sharing vs. Reliance upon Info Flow

The second ranked vulnerability is External Pressures, those influences not specifically targeting the firm that create business constraints or barriers. Issues relating to price pressures and environmental concerns both ranked in the top 10 of 40 vulnerability sub-factors. In regards to price pressures, an active business intelligence program is critical to anticipate pressures from market shifts, regulatory changes and product innovations – this was rated only a moderate capability (3.47 of 5.00). Other

efficiency programs designed to reduce the cost of procurement, production and distribution are critical to maintaining a competitive advantage in a price sensitive market. Current asset utilization can be improved (3.00 of 5.00), along with failure prevention (3.10) and waste elimination (3.44). Business intelligence was rated as a much higher capability by Commercial/Sales team members (see Figure G.3c). Threats from competitive innovations also rank as a significant vulnerability (3.75 of 5.00), while the associated capability of Adaptability in alternative technology development is only moderate (3.28 of 5.00). Investments in product research and development as well as process improvements can combine to create lower cost, greater functionality and more flexible processes to get new products to the market faster than competitors.

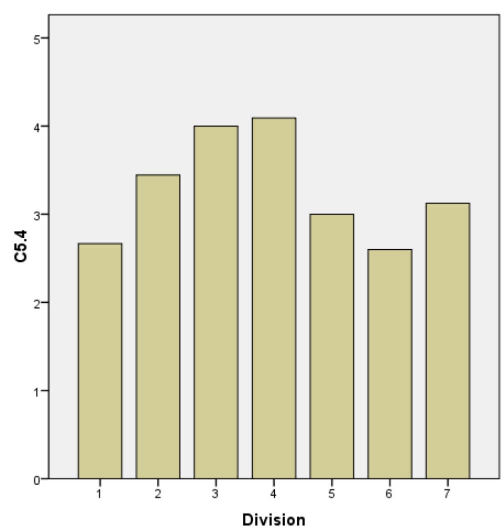

Figure G.6: Business Intelligence by Functional Area

In regards to environmental concerns, a capability that counteracts some aspects of environmental concerns is waste elimination – currently a moderate capability (3.44 of 5.00). Follow-on work with Company G will focus on more detailed recommendations to assessing and improving sustainment issues. Threats from government regulations are understandably a critical vulnerability (3.86 of 5.00) that Company G has balanced with a Top 10 capability of collaboration with government regulators (4.09 of 5.00).

The third-ranked vulnerability is Sensitivity, which means that Company G is dependent on carefully controlled conditions for product and process integrity. In this area, the symbolic profile of the brand, importance of product purity, complexity of operations, fragility of product during storage/handling and the concentration of production capacity ranked significantly high (all above 3.90 of 5.00). The profile of the "Company G" brand is an asset to the firm that must be protected. As expected, the purity of products and their fragility are also high vulnerabilities, and in such an environment a firm must maintain strict quality control of processes and protect facilities, especially where bottlenecks are present.

The fourth-ranked vulnerability is Resource Limits, constraints on output based on availability of the factors of production. Production capacity is a significant vulnerability in this category, scoring 4.25 of 5.00 and #6 of 40 vulnerability sub-factors. Recent trends towards increased production flexibility create smaller batches that reduce asset utilization. This low asset utilization (3.00) appears to be impacting production capacity. Therefore, process improvements to reduce "time per set-up" will allow for current levels of production flexibility and the return of needed capacity. New capital

investment in capacity may also be necessary based on future demand projections. Consider modernized assets that can provide improvements in change-over speed to meet production flexibility goals as consistent with the need to overcome a moderate vulnerability to unpredictability in customer demand (3.11 of 5.00).

Supplier capacity (3.87 of 4.00) is also a vulnerability of concern in the category of Resource Limits. Review of the major Supplier, also showed similar production capacity issues (4.13 of 5.00 and #2 of 40 vulnerability sub-factors), but not supplier related capacity issues (2.86 of 5.00). Therefore, the capacity bottleneck is within the Tier 1 Supplier. Company G's should consider evaluating the resilience of key suppliers, combined with partnership sessions directed on aligning supplier's strategies, process and metrics with Company G. This will also contribute to increased trust and communications between firms and with other Company G divisions. Higher levels of trust will benefit collaborative programs such as risk/reward sharing and collaborative information exchanges.

The final vulnerability factors, Supplier/Customer disruptions, Turbulence and Deliberate threats, ranked near or below the 3.00 "neutral" threshold. Details for all factors are found in the Tables G.3 and G.4.

Following the assessment of each factor, each team member was asked to report their perception of the relative importance of each of the measures. These questions were reserved for the end of the assessment to ensure that respondents were exposed to each of the vulnerability and capability factors in order to better determine their relative priorities. Results of the relative importance of vulnerabilities are shown in Figure G.7.

Two vulnerability factors stand out as most critical: Resource Limits and Supplier/Customer Disruptions. The implication is that Company G should concentrate on maintaining existing capabilities and improving new capabilities to anticipate and manage these issues. Emphasis on customer relationship management is critical to better manage the significant unpredictability in demand and its associated moderate scores of the frequency of customer disruptions.

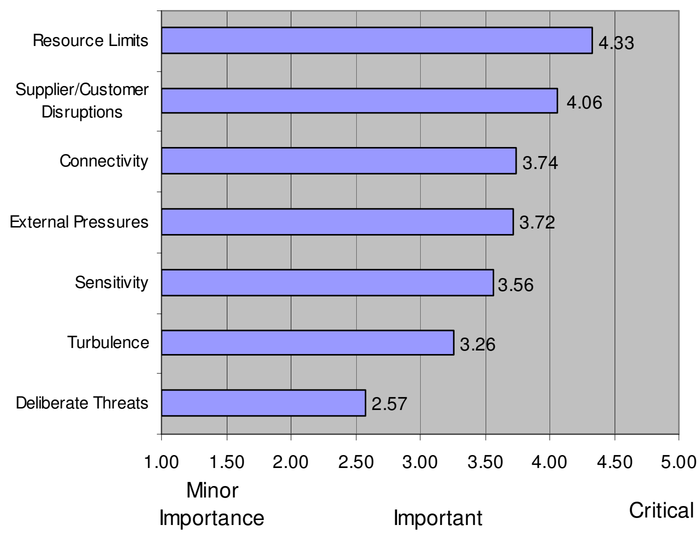

Figure G.7: Importance of Vulnerabilities

As vulnerabilities represent the fundamental factors that make an enterprise susceptible to disruptions, these factors are considered inherent in the enterprise's operating environment and therefore can not be affected in the short term. In the long term, strategic decisions altering the environment could radically change the supply chain, which would then require a re-evaluation. Therefore, the following section

provides recommendations based on the capability scores, which represent the methods that an enterprise can utilize to anticipate and overcome disruptions.

Capability Results

In order to combat vulnerabilities, research has shown that a supply chain must have the capabilities needed to overcome its vulnerabilities for long-term survival. These supply chain capabilities create the ability to anticipate and potentially prevent a disruption, mitigate the effects of a disruption or adapt with new, more profitable processes, products or services. Table G.2 and Figure G.8 summarize the capability scores for Company G's self-assessment. Detailed sub-factor rankings are presented in Table G.4.

Ranking	Capability	Factor Label	Average Score	Standard Deviation
1	Security	C13	4.11	0.46
2	Dispersion	C9	3.91	0.48
3	Organization	C11	3.85	0.57
4	Recovery	C8	3.69	0.57
5	Market Position	C12	3.67	0.42
6	Visibility	C5	3.60	0.70
7	Financial Strength	C14	3.53	0.52
8	Efficiency	C4	3.45	0.58
9	Anticipation	C7	3.36	0.67
10	Flexibility in Sourcing	C1	2.97	0.58
11	Collaboration	C10	2.97	0.64
12	Adaptability	C6	2.88	0.60
13	Flexibility in Order Fulfillment	C2	2.85	0.64
14	Capacity	C3	2.62	0.69

Table G.2: Capability Rankings

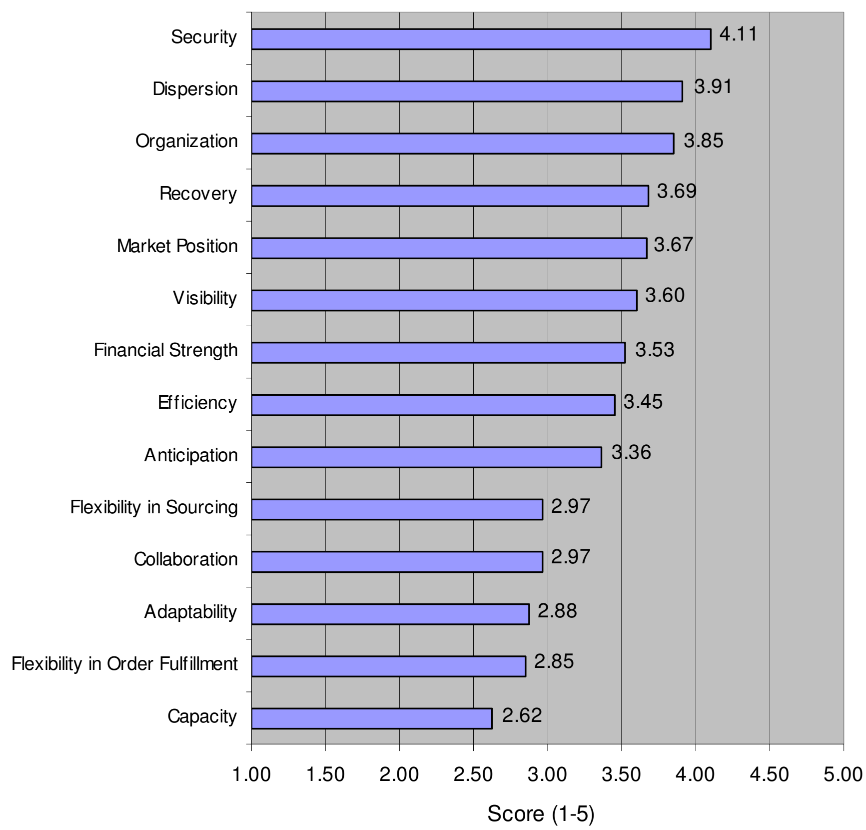

Figure G.8: Capability Scores

Company G's Resilience Team reported their strongest capability as Security. Sub-factors of Security are consistently high in all areas including strengths in cyber security, personnel security and access restrictions. One could argue that there is actually an over-expenditure on security, based on low scores for Deliberate Threats combined with the low level of importance placed on Deliberate Threats. Further studies of Supply Chain Resilience should investigate whether these low vulnerability scores are in fact an artifact of the successful Security capabilities in place at Company G.

Dispersion ranked 2nd as a strength within Company G's supply chain. Led by significant dispersion of markets (4.69 of 5.00), this factor also scored high in areas such as distributed production assets (3.94) and distributed leadership (3.91). This capacity is critical to avoiding single-point failures; however, considering the vast number of diverse products marketed by Company G, care should be taken to look at individual products and their associated supply chains individually. Any single node or single channel in a supply chain can be a weakness. In addition, whenever multiple product supply chains merge at any point (i.e. common supplier for single-sourced components or a shared distribution channel), significant oversight and precautions should be taken; in addition, redundancy and flexibility in sourcing built should be designed into the system.

Company G scored high in the Organization capability as well, "the human resource structures, policies, skills and culture." All sub-factors scored moderately high, ranging from accountability (4.08 of 5.00) to benchmarking (4.06) to creative problem solving (3.94). Organizational capabilities are critical to creating an environment and culture to facilitate resilience.

On the opposite extreme, Company G's lowest capability scores are in Capacity, Flexibility in Order Fulfillment, Adaptability, Collaboration and Flexibility in Sourcing. First, Capacity: availability of assets to enable sustained production levels. Reserve capacity scored the lowest of all 71 sub-factors (1.72 of 5.00). However, with high-value production assets it may not be cost-effective to create excess capacity. Other capabilities such as Flexibility in Order Fulfillment and Anticipation may limit exposure to this risk. Of particular note, supplier capacity and raw material availability are high

vulnerabilities (3.87 and 3.59, respectively), which again suggest benefits from improved collaborative planning and maximization of post-production flexibility.

Second, Flexibility in Order Fulfillment, the ability to quickly change outputs or the mode of delivery outputs, has lowest scores in multiple sourcing and reallocation (2.33 and 2.34 respectively). These capabilities combine organic production with outsourcing options to more cost-effectively meet peak demands. However, with very specialized products and limited alternative production, this may not be a feasible option for Company G. The third lowest rated element of Flexibility in Order Fulfillment is alternate distribution channels. These are critical post-production flexibility options that must be maintained due to low levels of excess production capacity. And although production postponement (2.85 of 5.00) may not be technically or economically feasible for many products, inventory management (3.26 of 5.00) is an important facet of flexibility. This capability is critical to knowing “where” product inventory is located (in conjunction with Visibility systems) and computing “how much” to stock (in conjunction with Anticipation and Collaboration). Without accurate data, recovery decisions can not be successfully implemented.

Third, Adaptability: the ability to modify operations in response to challenges or opportunities, is crucial to the concept of resilience. Company G reported only moderate ability to learn from experience (3.57 of 5.00) and alternate technology development (3.28). Lead-time reductions can produce significant improvements in customer service levels while helping to reduce inventory levels of finished goods (currently rated 2.91 of 5.00). Improvements can also be made in the area of re-routing of requirements (2.35 of

5.00) if alternate production facilities are available, even if only in a back-up capacity. And finally, seizing advantage from market changes (2.45 of 5.00) can be major capability to improving both customer satisfaction and market share. With the newly formed Market Facing organization, Company G is recommended to institutionalize programs to capture the fully potential of market disruptions. In summary, anticipation programs, production capacity and flexibility must be tied together to fully seize these opportunities.

Fourth, Collaboration: the ability to work effectively with other entities for mutual benefit, should be a major area of concern in Company G's very Sensitive operations. The team scored customer postponement of orders at 2.72 of 5.00. This is indicative of products critical to the customer's manufacturer process. However in many examples, firms report "contracted delivery dates" as the driving target for sales and logistics activities rather than the customer's actual need-date. Company G should consider formal methods of determining the customers' cost in relation to a disruption as compared to the cost options for recovery. In addition, Company G may consider forward locating more inventory, implementing Vendor Managed Inventory (VMI) or working with customers to carry higher levels of their on-hand inventory. These programs have been shown to increase customer service levels with costs off-set by increases in production asset utilization. Collaborative information sharing (3.07), product life cycle management (3.00) and risk sharing programs (2.70) can then be enhanced to further improve inventory availability while reducing costs. In view of the significant vulnerability to Connectivity, these issues should be addressed immediately.

Analyzing the importance of the 14 Capability factors provides interesting insight into the relative priorities that should be placed on each area, see Figure G.9. Company G is most focused on Capacity; however, this should not be overemphasized if more flexible options are available. A serious concern is the low level of importance placed on Security and Visibility. As mentioned earlier, successful security programs may have created an artificial sense of safety or complacency that should be addressed. Visibility is a crucial facilitator to many other capabilities such as Flexibility, Recovery and Collaboration and should not be discounted – in the information age, many firms share significant amounts of data but management must determine "what" data is shared and to "whom." Visibility between supply chain partners requires a significant amount of trust, but must be developed prior to an effective Collaboration program. Dispersion of high-value production assets appears to be of little concern due to the cost ramifications for Company G; however, security is very critical to these high-value assets.

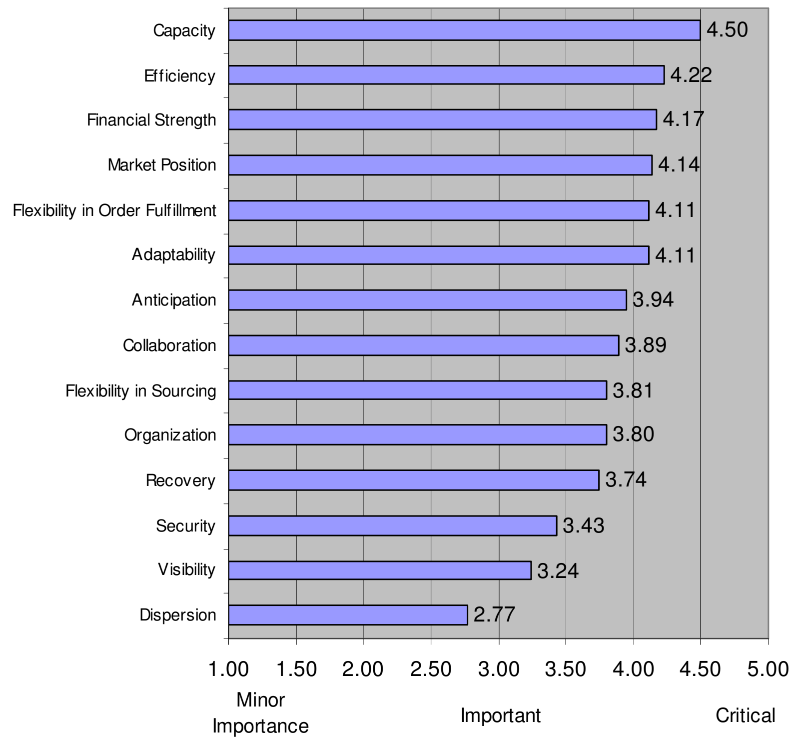

Figure G.9: Importance of Capabilities

Resilience Recommendations

Company G is commended for compiling an excellent Resilience Assessment Team. The team's composition matched well with the scope and goals determined by the project leaders. Through the team's investment of approximately 20 person-hours, a significant number of important issues were uncovered and discussed in this report. A summary follows:

- Connectivity threats require enhanced Collaboration, in forms of improved risk sharing, information sharing and life cycle management.

- External pressures require increased asset utilization, improved failure prevention programs and enhanced technology development to combat price pressures.
- Sensitivity concerns require stronger quality management programs and improved adaptability.
- Resource limits require greater post-production flexibility due to Capacity limitations.

Follow-on studies at the Center for Resilience and the Fisher College of Business are currently being conducted to empirically validate various types of tactical recommendations, as well as benchmarking between firms to gain greater fidelity in the assessment tool. To assist in accomplishing this effort, historical demand and performance data covering the time-period of this study was collected at Company G. Opportunities exist to continue collaboration in order to better define the successful capabilities that can be employed to overcome each specific vulnerability.

OSU has proposed "Phase II: Ensuring Supply Chain Resilience", which will consist of small-group interviews to evaluate recent disruptions. Consolidating Company G's data with data from other participating firms will culminate in a benchmarking report due in late summer 2008. These findings will further assist Company G in integrating resilience concepts into management improvement programs.

Ranking	Average	Label	Sub-factor	Factor
1	4.57	V3.3	Price pressures	External Pressures
2	4.53	V6.4	Reliance upon information flow	Connectivity
3	4.35	V5.8	Symbolic profile of brand	Sensitivity
4	4.31	V3.6	Environmental changes	External Pressures
5	4.29	V6.2	Import/export channels	Connectivity
6	4.25	V4.2	Production capacity	Resource Limits
7	4.15	V5.2	Importance of product purity	Sensitivity
8	4.03	V5.4	Complexity of process operations	Sensitivity
9	3.94	V5.3	Fragility	Sensitivity
10	3.91	V5.9	Concentration of capacity	Sensitivity
11	3.87	V4.1	Supplier capacity	Resource Limits
12	3.86	V3.2	Government regulations	External Pressures
13	3.76	V5.5	Reliability of equipment	Sensitivity
14	3.75	V3.1	Competitive innovation	External Pressures
15	3.67	V6.1	Scale and Extent of supply network	Connectivity
16	3.67	V6.3	Reliance upon specialty sources	Connectivity
17	3.59	V4.4	Raw material availability	Resource Limits
18	3.48	V6.5	Degree of Outsourcing	Connectivity
19	3.43	V3.4	Corporate responsibility	External Pressures
20	3.40	V2.6	Product liability	Deliberate Threats
21	3.30	V1.2	Fluctuations in currencies & prices	Turbulence
22	3.28	V5.1	Utilization of restricted materials	Sensitivity
23	3.23	V7.1	Supplier disruptions	Supplier/Customer Disruptions
24	3.19	V1.5	Unforeseen technology failures	Turbulence
25	3.19	V4.3	Distribution capacity	Resource Limits
26	3.15	V5.7	Visibility of disruption to stakeholders	Sensitivity
27	3.11	V1.1	Unpredictability in customer demand	Turbulence
28	3.06	V3.5	Social/Cultural changes	External Pressures
29	3.03	V7.2	Customer disruptions	Supplier/Customer Disruptions
30	2.81	V4.6	Human resources	Resource Limits
31	2.77	V4.5	Utilities availability	Resource Limits
32	2.63	V2.5	Industrial espionage	Deliberate Threats
33	2.59	V2.1	Terrorism & sabotage	Deliberate Threats
34	2.43	V2.3	Union activities	Deliberate Threats
35	2.34	V1.3	Exposure to geopolitical disruptions	Turbulence
36	2.30	V2.4	Special interest groups	Deliberate Threats
37	2.30	V5.6	Potential safety hazards	Sensitivity
38	2.08	V1.4	Exposure to natural disasters	Turbulence
39	2.03	V1.6	Pandemic	Turbulence
40	1.61	V2.2	Piracy & theft	Deliberate Threats

Table G.3: Vulnerabilities by Score Rank

Ranking	Average	Item	Sub-Factor	Factor
1	4.69	C9.5	Geographic dispersion of markets	Dispersion
2	4.33	C1.1	Common product platforms	Flexibility in Sourcing
3	4.28	C13.5	Cyber-security	Security
4	4.21	C13.6	Personnel security	Security
5	4.15	C13.2	Access restriction	Security
6	4.13	C13.3	Employee involvement in security	Security
7	4.09	C13.4	Collaboration with governments	Security
8	4.08	C11.2	Accountability	Organization
9	4.06	C11.5	Benchmarking/ Feedback – Learning Organization	Organization
10	4.00	C4.1	Labor productivity	Efficiency
11	4.00	C12.6	Communications	Market Position
12	3.97	C12.1	Brand equity	Market Position
13	3.95	C14.3	Insurance coverage	Financial Strength
14	3.94	C9.2	Distributed capacity & assets	Dispersion
15	3.94	C11.1	Creative problem solving culture	Organization
16	3.91	C9.3	Distributed leadership	Dispersion
17	3.91	C8.3	Crisis management	Recovery
18	3.90	C3.1	Backup energy sources/communications	Capacity
19	3.90	C7.3	Monitoring & Communicating deviations & near misses	Anticipation
20	3.83	C11.3	Diversity of skills & experience	Organization
21	3.83	C12.5	Relationships	Market Position
22	3.81	C8.1	Resource mobilization	Recovery
23	3.81	C5.2	Products, Assets, People	Visibility
24	3.79	C5.1	Information technology	Visibility
25	3.75	C13.1	Layered defenses	Security
26	3.72	C14.1	Financial reserves & liquidity	Financial Strength
27	3.68	C9.4	Location-specific empowerment	Dispersion
28	3.67	C4.4	Product/part variability reduction	Efficiency
29	3.67	C7.4	Recognition of early warning signals	Anticipation
30	3.67	C11.6	Culture of caring for employees	Organization
31	3.67	C12.3	Market share	Market Position
32	3.67	C14.2	Portfolio diversification	Financial Strength
33	3.57	C6.6	Learning from experience	Adaptability
34	3.56	C8.2	Communications strategy	Recovery
35	3.54	C2.3	Demand pooling	Flexibility in Order Fulfillment
36	3.53	C8.4	Consequence mitigation	Recovery
37	3.47	C11.4	Substitute leadership capacity	Organization
38	3.47	C5.4	Business intelligence gathering	Visibility
39	3.44	C4.3	Waste elimination	Efficiency
40	3.42	C7.2	Risk identification & prioritization	Anticipation

Continued

Table G.4: Capabilities by Score Rank

Table G.4 continued

41	3.38	C1.2	Product/service modularity	Flexibility in Sourcing
42	3.37	C12.2	Customer loyalty/retention	Market Position
43	3.32	C10.1	Collaborative forecasting	Collaboration
44	3.32	C7.5	Contingency planning/Preparedness	Anticipation
45	3.30	C5.3	Information exchange	Visibility
46	3.28	C6.4	Alternative technology development	Adaptability
47	3.26	C2.4	Inventory management	Flexibility in Order Fulfillment
48	3.26	C7.1	Demand forecasting methods	Anticipation
49	3.21	C12.4	Product differentiation	Market Position
50	3.10	C4.5	Failure prevention	Efficiency
51	3.07	C10.2	Collaborative information sharing	Collaboration
52	3.03	C14.4	Price margin	Financial Strength
53	3.00	C4.2	Asset utilization	Efficiency
54	3.00	C10.4	Product life cycle management	Collaboration
55	2.97	C7.6	Recognition of opportunities	Anticipation
56	2.96	C9.1	Decentralization of key resources	Dispersion
57	2.91	C6.5	Lead time reduction	Adaptability
58	2.85	C1.3	Multiple pathways & skills	Flexibility in Sourcing
59	2.85	C2.2	Delayed commitment/Production postponement	Flexibility in Order Fulfillment
60	2.72	C2.5	Alternate distribution channels	Flexibility in Order Fulfillment
61	2.72	C10.3	Postponement of orders	Collaboration
62	2.70	C10.5	Risk sharing with partners	Collaboration
63	2.68	C6.2	Strategic gaming & simulation	Adaptability
64	2.60	C3.2	Redundancy (Assets, labor)	Capacity
65	2.45	C6.3	Seizing advantage from disruptions	Adaptability
66	2.35	C6.1	Fast re-routing of requirements	Adaptability
67	2.34	C2.6	Reallocation	Flexibility in Order Fulfillment
68	2.33	C2.1	Multi-sourcing (peak vs. base)	Flexibility in Order Fulfillment
69	2.29	C1.5	Alternate suppliers/Outsourcing options	Flexibility in Sourcing
70	2.16	C1.4	Supply contract flexibility	Flexibility in Sourcing
71	1.72	C3.3	Reserve capacity (Materials, assets, labor)	Capacity

Case Studies

Single-Sourced Supply Failure
Company G, Disruption #1
(G1 – Supply-side)

Company G produces a specialized additive for unique applications. This product faces a highly seasonal demand pattern due to summer usage of the end product, with orders surging annually in March through May. A key ingredient in Company G's product is sole-sourced from a major supplier in Europe. This supplier operates a single plant due to historically low sales; capacity utilization has only been around 50 percent.

To support Company G as the sole user in North America, the supplier previously held inventory in the United States with reliable lead-times for delivery of only 1 week. However, demand in 2007 was less than forecasted by Company G, which triggered the supplier to centralize stock at the European plant to save on inventory carrying costs. Quoted lead-times were to rise to 8 weeks, using sea transportation to the USA, then truck to Company G's plant.

During the early stages of the 2008 seasonal demand, procurement continued to be shipped from US stockpiles until resources were depleted. However, due to poor communication between Company G and their supplier, the exact timing of the transition to European-sources was missed. Only when planners at Company G noticed a potential shut-down of the production line was the issue fully understood. Recovery actions were continually hampered by poor communications through the supplier's North American sales staff in Canada through to the production plant in Europe. Efforts to air ship

product directly to the plant resulted in a 45.6 percent per-unit cost increase and resulted in Company G loosing 9 days worth of production where its customers were directed to Company G's competitor for approximately $1 million in product.

Product Shortage
Company G, Disruption #2
(G2 – Production)

Company G planned for routine maintenance of a continuous-flow production facility in February 2008. However, during re-start several leaks were in plumbing were identified requiring repair. As the line was shut-down, removal of steam pressure from the heating lines also caused an inadvertent loss of steam to an interlinked processing line ("Line 2") causing product to solidify in the pipes. As repairs progressed passed the anticipated return-to-service date, Company G's follow-on processing line operated on reserve inventory of supplies until Line 2 could be thawed, then initial product had quality flaws for several days. Once Line 2's product was acceptable, the follow-on processing line was initiated at only operating at 50 percent capacity until Line 1 could be repaired – 18 days late, and not reaching full capacity due to start-up quality issues until another 6 days later. All sales were forced into a "pre-order" mode to best match customer orders with production schedules.

Compounding Company G's disruption was an unexpected surge in demand during the maintenance and repair periods. As the product under investigation is a secondary product, no excess capacity existed without producing excess amounts of the primary product. In addition, a precursor issue was a shortage of storage space which prevented additional stockpile of safety stock prior to the planned shut-down.

Outbound 3PL Provider Causes Delivery and Customs Delays

Company G, Disruption #3

(G3 – Demand-side)

Company G's product in this case study is shipped in bulk ISO containers from the production facility in the United States to customers around the world. Recent trends in vessel and container availability have increased transportation booking delays from a maximum of 7 days to average of 28 days. Company G's logistics systems did not anticipate this trend which began in mid-2007 not react to the increase lead-time requirements for over 5 months. Customers were still being quoted shorter lead-time and late deliveries became the norm.

Compounding the problem of late arrivals due to booking delays, for this specific customer in China, paperwork issues were stalling shipments in customs seriously impacting customer satisfaction and driving sales to competitors. Company G uses a third-party logistics firm to book ISO container lease and overseas vessel. An additional link was recently added to outsource the documentation for shipments to the pacific. This regional partner in Hong Kong experienced initial issues but is currently working effectively. However, paperwork for this customer in China continues to include major errors in on 50 percent of shipments, 80 percent of those errors are in the product "quantity" as listed in the Bill of Lading and carrier's manifest. Due to the extended supply chain connectivity, the end result has been 50 percent late deliveries to the customer.

Inhibiting recovery efforts, communications shortfalls within the distribution network are strained. Vessel owners do not update Company G directly with status information and tracking of shipments is sporadic. ISO tank company, Clearance house and customer's broker in China are all added nodes to the communications chain. Time-zone changes and culture issues have driven a reliance on e-mail communications, which is less effective in urgent communications; personal bonds are not strongly built as in domestic operations where Company G's staff is quick to "pick up the phone" in reaction to an urgent issue.

APPENDIX H

Focus Group Protocol (1)

"Ensuring Supply Chain Resilience"

Interviewer: __________________ Date: __________

Purpose: Ensure completeness and proper organization of OSU's framework for characterizing Supply Chain resilience

Method: On-site interviews with a cross-functional set of Limited Brands leaders to better understand how resilience is perceived, defined, measured and managed.

Objective: Develop a state-of-the-art Self-Assessment Tool that will allow business leaders to identify gaps, opportunities and priorities for improving resilience in their enterprise.

Goal: Strengthen the capacity of the supply chain enterprise to cope with a turbulent business environment.

Introductions: Interviewer and Subjects.

"Limited Brands has agreed to collaborate with The Ohio State University's Fisher College of Business and The Center for Resilience to study the Limited Brand's world-class Supply Chain and the characteristics creating a resilient Supply Chain. The purpose of this interview is to ensure completeness and proper organization of OSU's framework for characterizing Supply Chain resilience. The final objective is to develop a state-of-the-art Self-Assessment Tool that will allow business leaders to identify gaps, opportunities and priorities for improving resilience in their enterprise. Through this project, our goal is to strengthen the capacity of the enterprise to cope with a turbulent business environment.

"I am interviewing Thought Leaders from the spectrum of the Limited Brands' Supply Chain. I want to remind you that your identity is completely confidential and we truly

are seeking your honest views. Please feel free to break-in at any time if you have questions.

“This interview is expected to last approximately 90 minutes.

Name	Title	Division	Number of years in present position	Number of years with company	Phone

SECTION 1: Perception, definition and measurement of Resiliency

“Limited Brands is a demonstrated leader in global supply chain success. However, I think we can all agree that supply chains are vulnerable to change. Enterprise resilience is the capacity for complex business systems to survive, adapt and grow in the face of turbulent change – much like living systems. We hope to learn from your experience and insight the ways that you cope with disruptions that threaten business continuity and profitability.”

“What does resilience mean to you?” (open discussion)

“To help our understanding of the complexity of resilience, I would next like to discuss some specific examples of recent turbulence that has faced your organization and how you reacted.”

Leading questions (only if necessary):

1. What was a recent disruption that you’ve faced?
2. How and when did you notice the change?
3. What we’re your initial thoughts and actions?
4. Were you prepared? Were others in the company prepared? Were your supplier prepared?
5. What was your customers’ reaction?
6. How long did it take to overcome the disruption?
7. What was the immediate effect to your organization? to the company?

8. What was the long-term effect to your organization? to the company?
9. Did you return to your original state (processes, relationships, resources) or morph into a different state?

SECTION 2: Refining the Framework for Supply Chain Resilience

"Now that we have discussed your perceptions and experiences with resilience, I would like to take a few minutes to present our current framework for supply chain resilience. Then, we will discuss each item to improve on our completeness, clarity and format."

(present Overview of Framework handout, see below)

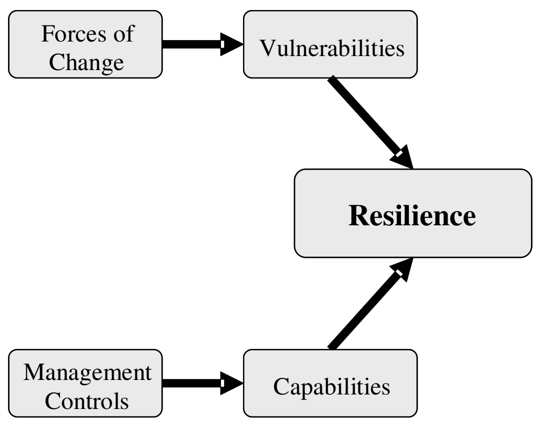

Figure H.1: Supply Chain Resilience Framework

"Enterprises constantly experience change. Therefore, in order to assess the enterprise's level of exposure to the forces of change, called vulnerabilities. We have characterized six (later "seven") categories of Vulnerability which generate risk to the organization:"

1. Turbulence
2. Deliberate threats
3. External pressures
4. Resource limits
5. Sensitivity
6. Connectivity
7. Supplier and Customer Disruptions

"In order to offset, or even directly combat an enterprise's vulnerabilities, we have framed 14 Supply Chain Capabilities which create the ability to survive, adapt and grow in the face of change."

1. Flexibility in Sourcing
2. Flexibility in Order Fulfillment
3. Availability
4. Efficiency
5. Adaptability
6. Visibility
7. Anticipation
8. Recovery
9. Decoupling
10. Collaboration
11. Market Position
12. Organization
13. Security
14. Financial Solvency

1. What do you think of these vulnerabilities?
    a. More?
    b. Less?
    c. Clearly defined?
2. What do you think of these capabilities:
    a. More?
    b. Less?
    c. Clearly defined?

3. Where do your examples of turbulence to the company that we discussed earlier fit into this model?
    a. Did we capture the vulnerabilities that you presented in your example?
    b. Did we capture the capabilities that you presented in your example?

"Now, a few questions to better understand the components of your enterprise and how you react to change."

1. What is your core business process?
    a. What factors are your processes vulnerable to?
    b. How do you assess or measure these vulnerability factors?
2. What are your primary relationships within the company? external to the company?
    a. Can you identify key ways in which you ensure effective relationships?
    b. What type of actions do you take when relationships are stressed?
3. What are your critical resources that allow you to do your job effectively?
    a. Describe some safeguards that you use to protect these resources?
    b. When damaged or otherwise unavailable, how do replace these critical resources? How quickly can you do this?

“Thank you very much for your insight into the Resiliency of your organization. Again, I appreciate your willingness to spend time delving into this important topic. Based on these interviews, we will be consolidating your inputs, along with our experiences and literature from other academics, into a Self-Assessment Tool. This tool will assist supply chain leaders to better identify gaps, opportunities and priorities for improving resilience, with the ultimate goal of guiding you in strengthening the capacity of your supply chain enterprise to cope with a turbulent business environment.”

APPENDIX I

SCRAM™ 1.1

Supply Chain Resilience Assessment & Management (SCRAM™)

A research project supported by:

The Fisher College of Business

and

The Center for Resilience
at The Ohio State University

www.resilience.osu.edu

1. Introduction

a. **Overview**: You are invited to participate in a unique questionnaire designed to assess the resilience of your supply chain.

b. **Our Goal:** To strengthen the resilience of the supply chain, giving the enterprise greater ability to cope with a turbulent business environment, and thus creating competitive advantage.

c. **Confidentiality:** Your responses to this assessment will be kept strictly confidential by the research team at The Ohio State University. Your honest and accurate assessment is important for gaining meaningful insights into supply chain resilience.

d. **Thank you** for participating in this project. Completion of the assessment should require approximately 30 minutes.

2. Your functional role within the Supply Chain

Select one from the list below:

- ☐ **Research and Development**
- ☐ **Marketing**
- ☐ **Purchasing**
- ☐ **Production**
- ☐ **Logistics**
- ☐ **Planning/Scheduling**
- ☐ **Finance/Accounting**
- ☐ **Sales**
- ☐ **Other** ________________

3. Project Overview

a. **The Problem:** The business environment is becoming more and more turbulent. Supply chain disruptions, whether an accident, natural disaster, security breach, competitive threat or shift in demand, can be costly in the short term and may have lasting adverse impacts. It is essential for companies with complex supply chains to develop a clear understanding of their supply chain vulnerabilities then to proactively strengthen their capabilities to anticipate, respond and adapt.

b. The Solution: Based on research in management, economics, ecology and sociology, the concept of **resilience** has emerged as a critical characteristic of complex, dynamic systems such as business enterprises. In the business context, we define **resilience** as *the capacity for an enterprise to survive, adapt and grow in the face of turbulent change***.**

Change not only presents threats to business continuity, but can also **create opportunities** for business value creation. When disruptions change the competitive landscape, a resilient company can often take advantage by introducing business innovations, increasing market share and enhancing its reputation.

c. The Framework: In order to analyze the myriad of issues that contribute to enterprise resilience, Ohio State has developed a structured framework, which captures the fundamental factors that make an enterprise susceptible to disruptions -- **Vulnerabilities** -- and compares them with attributes that enable an enterprise to anticipate and overcome disruptions -- **Capabilities**. We believe that continuously examining these factors and strengthening enterprise capabilities will help to maintain competitiveness..

d. Definitions: While completing the assessment, consider only the operations internal to (company name)**.** Therefore, while completing the assessment, consider your **products** as the (company name) product offering (… or list products specifically). Consider your **customers** to be only those companies or individuals that **you sell to directly.** In many cases, this will *not* be the end consumer of your product. Finally, consider your **suppliers** to be the complete set of firms outside of the firm supplying raw materials**,** finished products, components, equipment and services required for your operations.

4. Assessment

First, you will be asked to assess the **vulnerabilities** that currently challenge your supply chain operations. For each statement, indicate the extent of your agreement or disagreement based on your personal knowledge of your products, organization and operations. If you do not have personal knowledge of the subject, *select "Don't Know"*.

Part 1: Vulnerabilities

Turbulence "Environment characterized by frequent changes in external factors beyond your control"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
V1.1 – Our products face unpredictable demand shifts.	☐	☐	☐	☐	☐	☐
V1.2 – We depend on supplies and/or export markets that experience severe currency or price fluctuations.	☐	☐	☐	☐	☐	☐
V1.3 – Our imports or exports face recurring disruptions due to geopolitical turmoil.	☐	☐	☐	☐	☐	☐
V1.4 – Our facilities or markets are frequently exposed to severe natural disasters.	☐	☐	☐	☐	☐	☐
V1.5 – We regularly face unforeseen technology failures in our operations.	☐	☐	☐	☐	☐	☐
V1.6 – Our operations are susceptible to a potential health pandemic affecting our employees.	☐	☐	☐	☐	☐	☐

Deliberate Threats "Intentional attacks aimed at disrupting operations or causing human or financial harm"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
V2.1 – Our facilities or personnel may be targets of terrorism or sabotage.	☐	☐	☐	☐	☐	☐
V2.2 – Our products are regularly stolen or vandalized.	☐	☐	☐	☐	☐	☐
V2.3 – We depend on unionized labor which can be hostile to the firm.	☐	☐	☐	☐	☐	☐
V2.4 – Our operations are frequently impeded by Special Interest Groups.	☐	☐	☐	☐	☐	☐
V2.5 – Our products or technologies may be compromised by industrial espionage.	☐	☐	☐	☐	☐	☐
V2.6 – Our operations or products may face liability claims.	☐	☐	☐	☐	☐	☐

External Pressures "Influences, not specifically targeting the firm, that create business constraints or barriers"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
V3.1 – Our products are threatened by frequent competitive innovations.	☐	☐	☐	☐	☐	☐
V3.2 – Our operations and/or products are subject to stringent and/or changing government regulations.	☐	☐	☐	☐	☐	☐
V3.3 – Our products face strong price competition.	☐	☐	☐	☐	☐	☐
V3.4 – Public opinion can exert significant pressure on our operations.	☐	☐	☐	☐	☐	☐
V3.5 – Social or cultural changes have had significant impact on our ability to serve our markets.	☐	☐	☐	☐	☐	☐
V3.6 – Environmental concerns influence how we design our products and/or conduct our operations.	☐	☐	☐	☐	☐	☐

Resource Limits "Constraints on output based on availability of the factors of production"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
V4.1 – Our suppliers have limited capacity.	☐	☐	☐	☐	☐	☐
V4.2 – Our production capacity is limited.	☐	☐	☐	☐	☐	☐
V4.3 – We have limited access to capacity for distributing products.	☐	☐	☐	☐	☐	☐
V4.4 – Raw materials for our products are scarce or in high demand.	☐	☐	☐	☐	☐	☐
V4.5 – Utilities are over-extended and our utility infrastructure is poor.	☐	☐	☐	☐	☐	☐
V4.6 – We have difficulty recruiting and retaining highly skilled workers.	☐	☐	☐	☐	☐	☐

Sensitivity "Importance of carefully controlled conditions for product and process integrity"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
V5.1 – We depend on the use of regulated or restricted materials.	☐	☐	☐	☐	☐	☐
V5.2 – The quality of our products is highly dependent on the quality of our inputs/supplies.	☐	☐	☐	☐	☐	☐
V5.3 – Our products require strict storage or handling controls to maintain their purity and/or integrity.	☐	☐	☐	☐	☐	☐
V5.4 – Our production operations are very complex.	☐	☐	☐	☐	☐	☐
V5.5 – Some equipment in our operations is delicate or failure-prone.	☐	☐	☐	☐	☐	☐
V5.6 – Our workers sometimes operate in extreme or hazardous conditions.	☐	☐	☐	☐	☐	☐
V5.7 – Errors or deficiencies in our operations are highly visible to stakeholders.	☐	☐	☐	☐	☐	☐
V5.8 – Our products carry brand names that are important to protect.	☐	☐	☐	☐	☐	☐
V5.9 – Our suppliers or production facilities are geographically concentrated and/or co-dependent.	☐	☐	☐	☐	☐	☐

Connectivity "Degree of interdependence and reliance on outside entities"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
V6.1 – Our supply chain has a large number of members.	☐	☐	☐	☐	☐	☐
V6.2 – We are part of a globally distributed supply chain.	☐	☐	☐	☐	☐	☐
V6.3 – Many of our products require specialty components.	☐	☐	☐	☐	☐	☐
V6.4 – Continuous information flow is critical to regular operations.	☐	☐	☐	☐	☐	☐
V6.5 – We outsource our operations to many different suppliers.	☐	☐	☐	☐	☐	☐

Supplier/Customer Disruptions "Susceptibility of suppliers and customers to disruptions"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
V7.1 – Our suppliers frequently face significant disruptions.	☐	☐	☐	☐	☐	☐
V7.2 – Our customers frequently face significant disruptions.	☐	☐	☐	☐	☐	☐

Part 2: Capabilities

You will then assess the **capabilities** currently employed by your company to offset these vulnerabilities. Responses are in the same format as Part 1.

Flexibility in Sourcing "Ability to quickly change inputs or the mode of receiving inputs"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C1.1 – Our supplies are used in multiple finished goods.	☐	☐	☐	☐	☐	☐
C1.2 – Our finished goods use modular designs.	☐	☐	☐	☐	☐	☐
C1.3 – Our products can be made by a variety of machines and workers.	☐	☐	☐	☐	☐	☐
C1.4 – Our supply contracts can be easily modified to change specifications, quantities and terms.	☐	☐	☐	☐	☐	☐
C1.5 – We have many alternate sources for key inputs.	☐	☐	☐	☐	☐	☐

Flexibility in Order Fulfillment “Ability to quickly change outputs or the mode of delivery outputs”	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don’t Know
C2.1 – We can quickly increase capacity of storage and distribution services.	☐	☐	☐	☐	☐	☐
C2.2 – We currently delay final production of finished goods until close to the time that customers place orders.	☐	☐	☐	☐	☐	☐
C2.3 – We pool inventory for a wide variety of customers at centralized locations.	☐	☐	☐	☐	☐	☐
C2.4 – We have a sophisticated inventory management system that regularly computes both safety stock and cycle stock at all storage and retail locations.	☐	☐	☐	☐	☐	☐
C2.5 – We can quickly change the routing and mode of transportation for outbound shipments.	☐	☐	☐	☐	☐	☐
C2.6 - We can quickly reallocate orders to alternate suppliers and reallocate jobs between different production units.	☐	☐	☐	☐	☐	☐

Capacity “Availability of assets to enable sustained production levels”	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don’t Know
C3.1 – We have reliable back-up utilities (electricity, water, communications)	☐	☐	☐	☐	☐	☐
C3.2 – We maintain access to duplicate or redundant facilities and equipment.	☐	☐	☐	☐	☐	☐
C3.3 – We have significant excess capacity of materials, equipment and labor to quickly boost output if needed.	☐	☐	☐	☐	☐	☐

Efficiency "Capability to produce outputs with minimum resource requirements"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C4.1 – Our labor productivity is very high.	☐	☐	☐	☐	☐	☐
C4.2 – Our assets are uniformly utilized with no limiting bottlenecks.	☐	☐	☐	☐	☐	☐
C4.3 – We produce products with little variability in quality.	☐	☐	☐	☐	☐	☐
C4.4 – We have effective preventative maintenance programs.	☐	☐	☐	☐	☐	☐
C4.5 – Our equipment is very reliable.	☐	☐	☐	☐	☐	☐

Visibility "Knowledge of the status of operating assets and the environment"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C5.1 – We have information systems that accurately track all operations.	☐	☐	☐	☐	☐	☐
C5.2 – We have real-time data on location and status of supplies, finished goods, equipment and employees.	☐	☐	☐	☐	☐	☐
C5.3 – We have regular interchange of information among suppliers, customers and other external sources.	☐	☐	☐	☐	☐	☐
C5.4 – We have effective Business Intelligence gathering programs.	☐	☐	☐	☐	☐	☐

Adaptability "Ability to modify operations in response to challenges or opportunities"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C6.1 – We can quickly reallocate orders to alternate suppliers and reallocate jobs between different production facilities.	☐	☐	☐	☐	☐	☐
C6.2 – We use strategic gaming and simulations to design more adaptable processes.	☐	☐	☐	☐	☐	☐
C6.3 – We excel at seizing advantages from changes in the market.	☐	☐	☐	☐	☐	☐
C6.4 – We develop innovative technologies to improve operations.	☐	☐	☐	☐	☐	☐
C6.5 – We continually strive to further reduce lead-times for our products.	☐	☐	☐	☐	☐	☐
C6.6 – We effectively employ continuous improvement programs.	☐	☐	☐	☐	☐	☐

Anticipation "Ability to discern potential future events or situations"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C7.1 – We effectively employ demand forecasting methods.	☐	☐	☐	☐	☐	☐
C7.2 – We have a formal risk identification and prioritization process.	☐	☐	☐	☐	☐	☐
C7.3 – We monitor deviations to normal operations, including near misses.	☐	☐	☐	☐	☐	☐
C7.4 – We monitor and recognize early warning signals of possible disruptions.	☐	☐	☐	☐	☐	☐
C7.5 – We have detailed contingency plans and regularly conduct preparedness exercises and readiness inspections.	☐	☐	☐	☐	☐	☐
C7.6 – We recognize new business opportunities and take immediate steps to capitalize on them.	☐	☐	☐	☐	☐	☐

Recovery "Ability to return to normal operational state rapidly"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C8.1 – We can quickly organize a formal response team of key personnel, both on-site and at the corporate level.	☐	☐	☐	☐	☐	☐
C8.2 – We have an effective strategy for communications in a variety of extraordinary situations.	☐	☐	☐	☐	☐	☐
C8.3 – We are very successful at dealing with crises, including addressing public relations issues.	☐	☐	☐	☐	☐	☐
C8.4 – We take immediate action to mitigate the effects of disruptions, despite the short-term costs.	☐	☐	☐	☐	☐	☐

Dispersion "Broad distribution or decentralization of assets"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C9.1 – Our key inputs are sourced from a decentralized network of suppliers.	☐	☐	☐	☐	☐	☐
C9.2 – Our production facilities are distributed at various locations.	☐	☐	☐	☐	☐	☐
C9.3 – Our senior leaders are based at a variety of different locations.	☐	☐	☐	☐	☐	☐
C9.4 – Our organization empowers on-site experts to make key decisions, regardless of level of authority.	☐	☐	☐	☐	☐	☐
C9.5 – Our products are sold to customers in a variety of geographic locations.	☐	☐	☐	☐	☐	☐

Collaboration "Ability to work effectively with other entities for mutual benefit"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C10.1 – We effectively employ collaborative demand forecasting techniques using shared data.	☐	☐	☐	☐	☐	☐
C10.2 – Our data flows transparently between supply chain members, with full access by all firms to facilitate collaborative decision making.	☐	☐	☐	☐	☐	☐
C10.3 – Our customers are willing to delay orders when our production capacity is hampered.	☐	☐	☐	☐	☐	☐
C10.4 – We have proactive product life-cycle management programs that strive to reduce both costs and risks.	☐	☐	☐	☐	☐	☐
C10.5 – Our firm invests directly in our suppliers' or customers' operations, as well as other actions to share risks.	☐	☐	☐	☐	☐	☐

Organization "Human resource structures, policies, skills and culture"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C11.1 – We strongly encourage creative problem solving.	☐	☐	☐	☐	☐	☐
C11.2 – We strictly enforce individual accountability for performance.	☐	☐	☐	☐	☐	☐
C11.3 – We train employees in a wide variety of skills.	☐	☐	☐	☐	☐	☐
C11.4 – We are capable of filling leadership voids very quickly.	☐	☐	☐	☐	☐	☐
C11.5 – We are a learning organization, regularly using feedback and benchmarking tools.	☐	☐	☐	☐	☐	☐
C11.6 – We have a strong culture of caring for employees.	☐	☐	☐	☐	☐	☐

Market Position "Status of a company or its products in specific markets"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C12.1 – Our brands have excellent customer recognition and a strong reputation for quality.	☐	☐	☐	☐	☐	☐
C12.2 – Our customers are very loyal to our products.	☐	☐	☐	☐	☐	☐
C12.3 – Our products command a significant share of the market.	☐	☐	☐	☐	☐	☐
C12.4 – Our customers can clearly differentiate our products from competitors' products.	☐	☐	☐	☐	☐	☐
C12.5 – Our firm has strong, long-term relationships directly with each of our customers.	☐	☐	☐	☐	☐	☐
C12.6 – Representatives of our firm communicate effectively with our customers.	☐	☐	☐	☐	☐	☐

Security "Defense against deliberate intrusion or attack"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C13.1 – We employ layered defenses and do not depend on a single type of security measure.	☐	☐	☐	☐	☐	☐
C13.2 – We use stringent restrictions for access to facilities and equipment.	☐	☐	☐	☐	☐	☐
C13.3 – We have active security awareness programs that involve all personnel.	☐	☐	☐	☐	☐	☐
C13.4 – We effectively collaborate with government agencies to improve security.	☐	☐	☐	☐	☐	☐
C13.5 – We have a high level of information systems security.	☐	☐	☐	☐	☐	☐
C13.6 – We use a variety of personnel security programs such as awareness briefings, travel restrictions and threat assessments.	☐	☐	☐	☐	☐	☐

Financial Strength "Capacity to absorb fluctuations in cash flow"	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree	Don't Know
C14.1 – We have significant financial reserves to cover all potential needs.	☐	☐	☐	☐	☐	☐
C14.2 – Our financial portfolio is very diverse.	☐	☐	☐	☐	☐	☐
C14.3 – We have significant insurance coverage for facilities, equipment, goods and personnel.	☐	☐	☐	☐	☐	☐
C14.4 – We sell our products at a relatively high margin.	☐	☐	☐	☐	☐	☐

Part 3: Importance of Factors

Finally, for all main factors presented in Parts 1 and 2, you will be asked to rate the relative level of **importance** for each factor. Response choices will be in the form of “Minor Importance,” “Important,” or “Critical.”

Vulnerabilities	Minor Importance	…..	Important	…..	Critical	Don’t Know
Turbulence	☐	☐	☐	☐	☐	☐
Deliberate Threats	☐	☐	☐	☐	☐	☐
External Pressures	☐	☐	☐	☐	☐	☐
Resource Limits	☐	☐	☐	☐	☐	☐
Sensitivity	☐	☐	☐	☐	☐	☐
Connectivity	☐	☐	☐	☐	☐	☐
Supplier/Customer Disruptions	☐	☐	☐	☐	☐	☐

Capabilities	Minor Importance	…..	Important	…..	Critical	Don't Know
Flexibility in Sourcing	☐	☐	☐	☐	☐	☐
Flexibility in Order Fulfillment	☐	☐	☐	☐	☐	☐
Capacity	☐	☐	☐	☐	☐	☐
Efficiency	☐	☐	☐	☐	☐	☐
Visibility	☐	☐	☐	☐	☐	☐
Adaptability	☐	☐	☐	☐	☐	☐
Anticipation	☐	☐	☐	☐	☐	☐
Recovery	☐	☐	☐	☐	☐	☐
Dispersion	☐	☐	☐	☐	☐	☐
Collaboration	☐	☐	☐	☐	☐	☐
Organization	☐	☐	☐	☐	☐	☐
Market Position	☐	☐	☐	☐	☐	☐
Security	☐	☐	☐	☐	☐	☐
Financial Strength	☐	☐	☐	☐	☐	☐

APPENDIX J

Focus Group Protocol (2)

"Disruption Case Study"
for
Ensuring Supply Chain Resilience

Disruption Title: ____________________________________ Date: __________

Interviewer: __________________ Company: ________________

Purpose: Identify critical linkages between vulnerabilities and the successful application of capabilities using OSU's Supply Chain Resilience framework.

Method: On-site focus groups composed of cross-functional leaders involved in recent disruptions to better understand how resilience can be successfully managed.

Objective: For each vulnerability, develop a set of successful capabilities that can provide managerial direction based on the results of the SCRAM™ self-assessment in order to improve resilience in their supply chain.

Goal: Creating supply chain resilience as a competitive advantage through the ability to efficiently and effectively cope with a turbulent business environment.

Part I : Introduction

- Introduce interviewer and participants.

"(company name) has agreed to collaborate with The Ohio State University's Fisher College of Business and The Center for Resilience to study the (company name) supply chain and the characteristics creating a resilient Supply Chain. The purpose of this focus group is to extract from your experience during (disruption identification) in order to

develop successful rules for applying supply chain resilience. Through this project, our goal is to strengthen your supply chain's ability to cope with the turbulent business environment."

"You have been selected as key players during this recent disruption. I want to ensure you that your remarks are completely confidential, as records of your responses will NOT have any reference that could directly identify you. Your participation in this project is completely voluntary. You can refuse to answer any questions, or withdraw from the Focus Group at any time without penalty or repercussion."

"This interview is expected to last 3 hours, with a break in the middle."

"Do you have any questions at this time?"

"Based on the overview provided, do you consent to participate in the study? I would like to record the audio of our discussion for the sole purpose of accurately documenting your responses. This will only be used by the research team for transcriptions, if needed. Do you have any objections to having our discussion recorded?"

{Begin recording.}

"Today is (date) at (time), with (company's name), discussing (disruption). All parties present have consented to participate in this Focus Group and to this audio recording."

Disruption under Study (complete this section in advance if possible)

Title: ____

Date: ___________________ Duration: ___________

Location: ________________

Background Information

Company: ______________

# of Employees: ____________ Annual Sales in $: ______________

Industry: _________________ Major Products/Services: _______________

Participant #1:

Name: ___________________ Division (Function): ______________

Job Title: _________________ Years in Position: ____________

Years in Function: ___________ Years with Company: ______________

Contact Information (phone/e-mail): ___________________________________

Participant #2:

Name: ____________________ Division (Function): _______________
Job Title: __________________ Years in Position: ________________
Years in Function: ___________ Years with Company: ______________
Contact Information (phone/e-mail): ____________________________________

Participant #3:

Name: ____________________ Division (Function): _______________
Job Title: __________________ Years in Position: ________________
Years in Function: ___________ Years with Company: ______________
Contact Information (phone/e-mail): ____________________________________

Participant #4:

Name: ____________________ Division (Function): _______________
Job Title: __________________ Years in Position: ________________
Years in Function: ___________ Years with Company: ______________
Contact Information (phone/e-mail): ____________________________________

Part II: Evaluation of a Disruption – Identification, Mitigation and Adaptation

"This first part of our discussion will focus on the periods BEFORE, DURING and AFTER the {disruption title}."

1. Before the disruption
    a. When was the disruption first identified?
    b. How did it actually begin?
    c. Did you have any warning?
    d. How was the disruption first identified?
    e. Who were the first to identify the problem? Who else was affected?

2. Severity and frequency of the impact of the disruption
    a. What was the immediate impact of the disruption?
    b. When, if at all, did your customers notice any negative impacts? How?
    c. Are your customers the end consumer?
        i. Yes.
        ii. No. When, if at all, was your end consumer first impacted? How?
    d. Does this type of event happen often?
        i. Yes – How frequently does this type of disruption happen?
        ii. No – Could it happen again?

3. During the disruption
    a. What was the initial response to the disruption?
    b. Was this completely successful?
        i. Yes – Were there any other responses taken later?
        ii. No – What other responses were necessary?
    c. Did any of your actions make the problem worse?
    d. Was your primary concern the length of time that the disruption would last or the severity of the disruption (i.e., minimize impact for a longer period, or short but severe)?
    e. Were you able to quantify the total impact of the disruption?
        i. Financial?
        ii. Performance?
        iii. Customer service/satisfaction?
    f. Once the initial disruption was resolved, were there any longer-term impacts? Were there any changes that were made?

4. Causes
    a. Did you attempt to analyze the root cause of this disruption?
        i. Yes – If so, what was it?
        ii. No – Why not? (skip b)
    b. How was this cause related to:
        i. Characteristics of your product?
        ii. Aspects of your production process?
        iii. Factors of your distribution network?

5. Learning from the disruption
    a. What did your company learn from this disruption?
    b. How did the firm change following this disruption (policy, structure, etc.)?
    c. How long did it take to implement these changes?
    d. Have these changes become 'permanent' or have procedures reverted to previous methods?

Reliability questions: 1d, 3a, 5b (single hold-out subject via phone/e-mail)

BREAK

Part III: Redesigning the Supply Chain

"This section of the discussion will focus on measures that can be used to prevent or mitigate the effects of negative changes. Think of your earlier comments about {disruption title} but also any other events that have occurred recently."

1. Internal Processes
    a. Preparation:
        1. What are the methods that you use to prepare for potential disruptions?
        2. What types of security do you employ to protect against threats? (natural disasters, stock-outs, deliberate threats)
    b. Anticipation:
        1. How do you anticipate disruptions?
    c. Response
        1. What are the first steps that taken when a disruption is discovered?
        2. What are key roles that you play during recovery operations?
        3. Do you inform your customers of current or projected disruptions?
        4. Is your customer is the end consumer?
            1. Yes.
            2. No – Do you inform final consumers of current or projected disruptions?
        5. How do you use the media during crises?
        6. Are your preparedness plans used during recovery?
            1. Yes – Are they typically accurate in describing the situation that actually occurred? Are the planned solutions usually the best courses of actions when needed, or are they heavily modified each time?
            2. No.
2. Suppliers
    a. How can your suppliers help you to be prepared for a disruption?
    b. How can your suppliers help you respond to an event?
    c. Do your suppliers provide any insight on future events or trends?
3. Customers
    a. How can your customers help you to be prepared for a disruption?
    b. How can your customers help you respond to an event?
    c. Do your customers provide any insight on future events or trends?
4. Distributors
    a. How can your distributors help you respond to an event?

5. Others
    a. Who else can assist you in responding to an event?
6. Learning
    a. Following a disruption, do you discuss the event and create an after-actions report?
        1. Yes – Who is involved in the discussion? When is it held?
        2. No. Skip to d.
    b. What are some key aspects of an "After Actions report"?
    c. Are the lessons learned communicated to the entire workforce? How?
    d. What types of issues can impede implementation of improvements?

"So far we have been discussing **disruptions** which are negative influences. Change in the business world can also create positive affects for your firm. For example, product innovations may open new markets, a parts shortage at your competitor may boost your sales, or a change to the distribution network can reduce your operating costs."

7. Using positive change to create opportunities
    a. How do you anticipate positive change?
    b. What are some ways that you create positive change?

(Note: Reliability questions: 1a1, 2c, 6a, 7b [single hold-out subject via phone/e-mail].)

"Thank you very much for your insight into the resilience of your organization. I appreciate your willingness to spend time delving into this important topic. Based on these interviews, we will be consolidating your inputs, along with those from other groups within (company name) and other firms participating in the study. Combining these results with your SCRAM self-assessment will assist supply chain leaders to better identify gaps, opportunities and priorities for improving resilience, with the ultimate goal of guiding you in strengthening the capacity of your supply chain to cope with a turbulent business environment. Thank you again for your valuable time today."

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